Rose Atoll 1993 Shipwreck Restoration Status Report

June 2012

Summary

A 1993 oil spill from a shipwreck damaged natural resources at Rose Atoll National Wildlife Refuge. The spill killed many invertebrates and a substantial area of crustose coralline algae (CCA), the primary reef building organism at Rose Atoll. This led to a bloom of invasive algae and cyanobacteria which prevented the natural recovery of the CCA and invertebrates. Additionally, iron from the metallic debris from the ship wreck 'fertilized' the invasive species, creating an environment that maintained the invasive species and prevented the recovery of the reef (**Figures 1, 2 and 3)**. A reef dominated by invasive species instead of CCA is greatly weakened, making a breach far more likely. A breach would drastically change the flow dynamics of the atoll, likely leading to the destruction of Rose Island and Sand Island, vital breeding areas for threatened green turtles and several species of federally protected seabirds.

In 2001, the Fish and Wildlife Service (FWS) prepared a Restoration Plan in accordance with Natural Resource Damage Assessment regulations. FWS found that removal of the remaining metallic debris was mandatory if the reef was to recover (USFWS & DMWR 2001). In 2003, the National Pollution Funds Center (NPFC) agreed to fund the restoration and monitoring efforts with FWS as the lead administrative trustee.

NPFC funds have been instrumental in the removal of the metallic debris and the recovery of the reef. Due to the extremely remote location of Rose Atoll and the difficulties involved in working in a high energy intertidal system, debris removal required several expeditions to Rose Atoll and took place between 1999 and 2007. There was a follow up debris removal expedition in 2010 that removed the last remaining pieces of debris. The removal of the iron has returned environment conditions to a state where the reef is recovering from the iron induced phase shift. Such ecological shifts have been documented at several remote Pacific atolls as a result of ship wrecks (Kelly et al 2011) and depending on conditions may become permanent shifts.

Monitoring activities to date have documented the effects of the spill and recovery actions on the reef and ecosystem. As iron has been removed, the invasive species are receding and the reef is beginning to recover. Due to the constant flow of outside ocean water, recovery has progressed most rapidly on the fore reef, followed by the reef crest, with the lagoon slowest to recover. During visual inspections in February 2012 and April 2012, there was far less invasive species cover on the fore reef, and a clear decline in invasive cover on the reef crest. The patch reefs in the lagoon still had substantial cyanobacteria cover and will likely take several more years to recover.

Monitoring activities will continue until 2017, ten years after the removal of the metallic debris as specified in the Restoration Plan. FWS will continue monitoring the same transects for iron, algae, CCA, urchins, sea cucumbers, corals and giant clams. FWS will work with universities and other researchers to analyze data we have collected but have not been able to analyze due to personnel constraints. Additionally, FWS is developing a partnership with NOAA Coral Reef Ecosystem Division (CRED) to conduct specific analyses of their extensive data sets on corals, fish, CCA and other aspects of Rose Atoll dating back to 2002.

Figure 1. Rose Atoll before the grounding (left) and Rose Atoll after the grounding (1994) (Right). Note the discoloration where the cyanobacteria impacted the CCA.

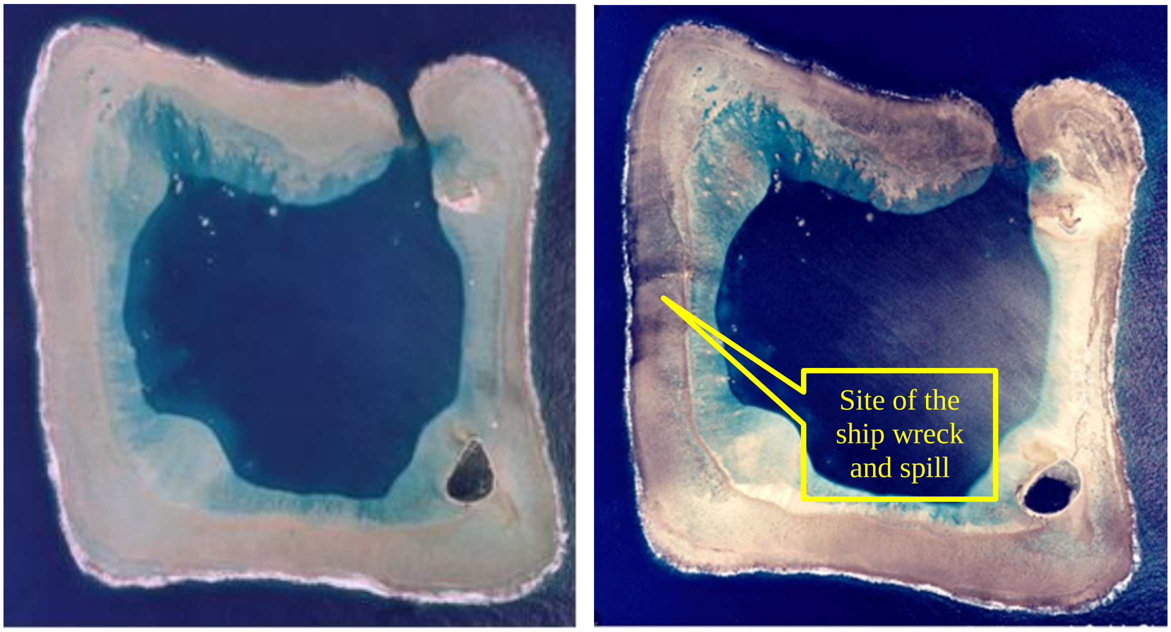


Figure 2. Rose Atoll in 2010 showing substantial decreases in invasive algae species as a result of the removal of iron.

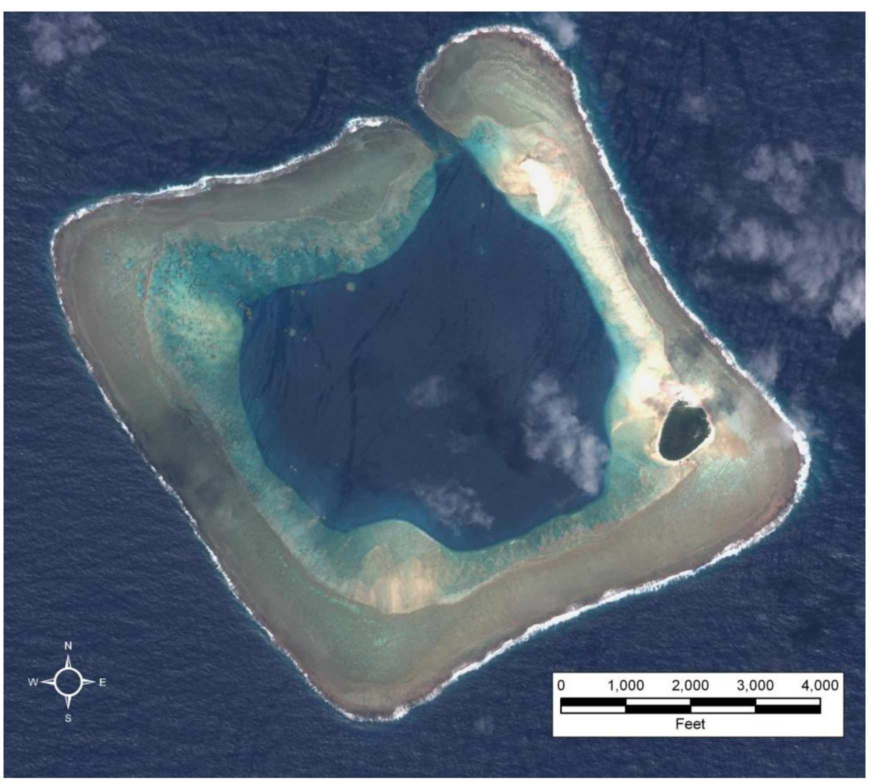


Figure 3. Outer reef slope survey stations along the atoll's west side; SW1(Stn-7) is the site of 1993 vessel grounding (Schroeder et al. 2008).

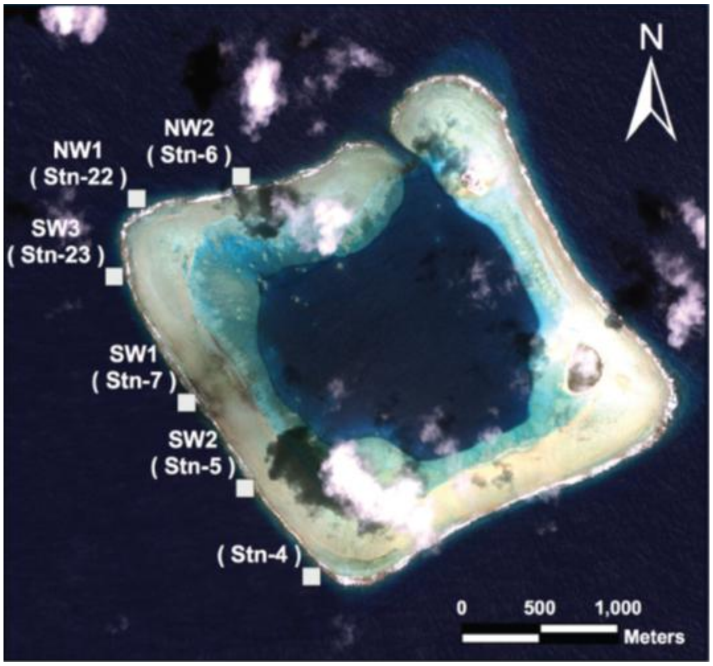
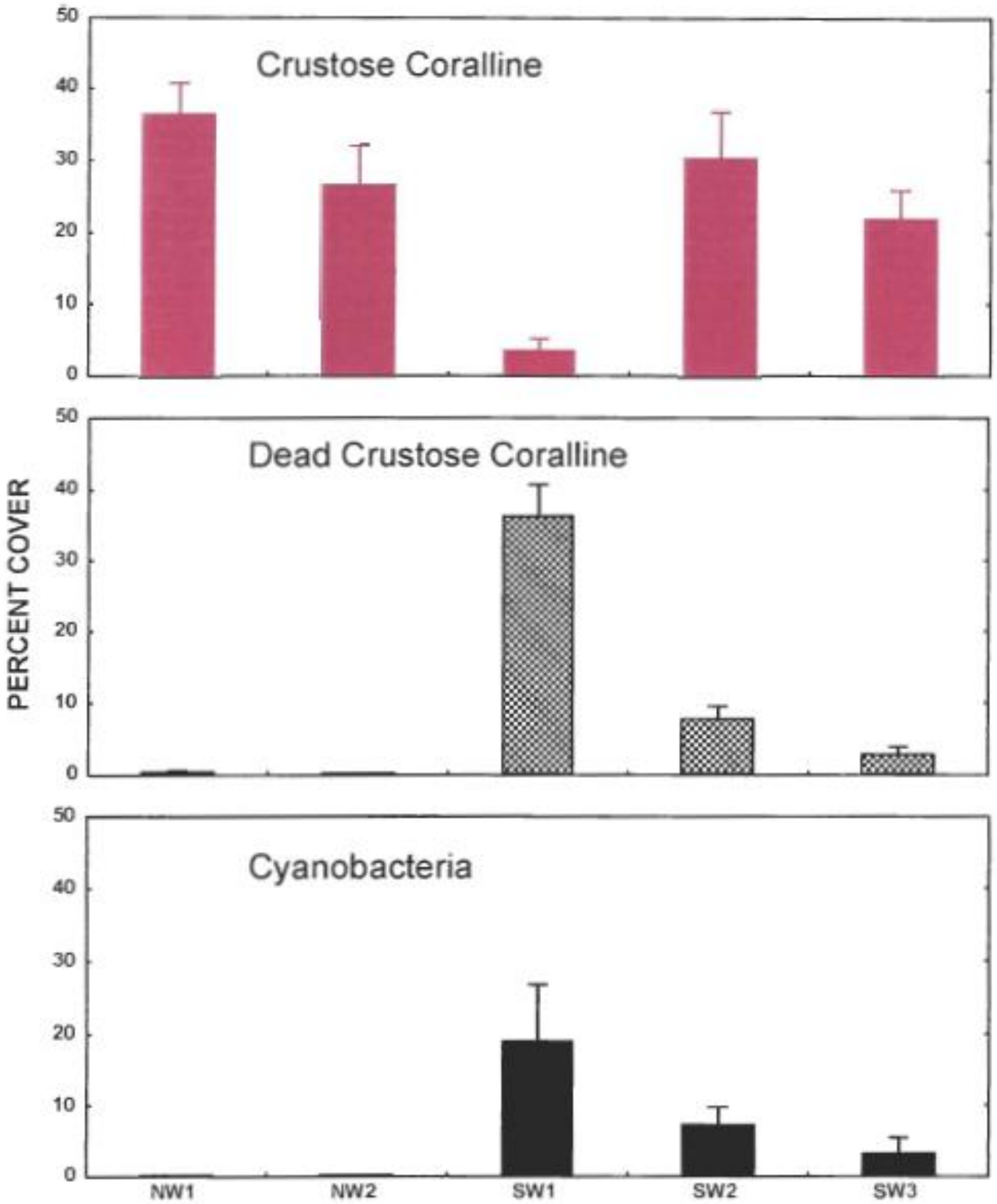


Figure 4. The Jin Shaing Fa October 1993 after running aground on the Southwest arm of Rose Atoll

Figure 5. The reef flat in 1994, showing extensive algae cover and pieces of the Jin Shiang Fa.

Figure 6. The engine and other large pieces of the Jin Shiang Fa on the fore reef in 1999.

Figure 7. Abundance of live and dead CCA and cyanobacteria on the outer reef slope at three sites on the SW arm and two sites on the NW arm of Rose Atoll approximately one year after the ship grounding. SW1 represents the site of grounding (from Green et al. 1997).



Background

On October 14, 1993, the 122 foot Taiwanese longline fishing vessel Jin Shiang Fa ran hard aground on the seaward edge of the southwest arm of Rose Atoll National Wildlife Refuge (NWR) (**Figure 4**). The ship had refueled in Pago Pago Harbor less than 24 hours earlier and was in transit to an unspecified fishing area (USFWS 1996a). The vessel broke up in November 1993 before a salvage tug boat could reach the atoll, resulting in the release of over 100,000 gallons of diesel fuel and 500 gallons of lube oil (Barclay 1993). The diesel and oil were discharged into the marine environment where prevailing currents carried the bulk of the material across the reef flat and into the lagoon. Additionally, with the break-up of the vessel, over 300 tons of metallic and other debris were deposited on the reef **(Figures 5 and 6)**.

After the oil spill, biological conditions on the reef deteriorated rapidly. The spill killed a large area of crustose coralline algae (CCA) the primary reef building organisms of Rose Atoll. The die off took place near the wreck site as well as near the channel draining the lagoon **(Figures 1-3 and 7)**. Invasive species of cyanobacteria and articulated coralline algae quickly began colonizing the areas of the reef injured by the spill**.** Data collected in the years following the spill indicates that iron released into the water from corroding metal wreckage stimulated the growth of these invasive algae, which prevented resources injured by oil from returning to baseline conditions. The invasive species spread to areas of the atoll that were initially unaffected by the incident, where they overgrew and killed the CCA. Other documented spill-related injuries that occurred shortly after the spill include the death of numerous giant clams, sea cucumbers and sea urchins (Green et al. 1997). Additionally, the composition of the local fish community was altered by the incident (Schroeder et al. 2008).

The U.S. Fish and Wildlife Service (USFWS) and the American Samoa Department of Marine and Wildlife Resources (DMWR) are the Natural Resource Trustees for Rose Atoll (Trustees). In 2001, they expressed concern that the very structure of the atoll could become seriously weakened in those areas where invasive species had replaced the reef building CCA (USFWS & DMWR 2001). The Trustees surmised that if the reef were weakened further by the degradation of the reef building community, it could become breached, resulting in a significant change in water circulation patterns across the atoll, and the eventual destruction of Rose and Sand Islands through increased erosion. If these islands were destroyed, it would mean the loss of the most important resting and nesting habitat for federally protected seabirds and the federally listed green sea turtle in American Samoa.

The goals of the Trustees' 2001 *Final Restoration Plan for Rose Atoll National Wildlife Refuge* (Restoration Plan) was to stop the ongoing, spill-related injuries to the atoll, allow the natural resources of the atoll to return to their baseline conditions, and to monitor this return to baseline conditions in order to apply adaptive management principles (USFWS & DMWR 2001). Because emergency restoration actions taken in July-August 1999 and April 2000 indicated that the removal of metal debris would stop the spread and dominance of the invasive species, the Trustees concluded that the only way to halt the ongoing injury caused by the *Jin Shiang Fa* oil spill was to remove the remaining metal debris. The removal of metal debris was considered a prerequisite to implementing any other restoration alternative. Debris removal was completed in 2007 and will be followed by 10 years of monitoring.

Removal of Metallic and Other Debris

When salvage operations began in November 1993, the majority of the ship's pieces covered about 9,000 m^2 of reef flat, but ship debris was scattered over an estimated 175,000 m^2 of reef flat and lagoon terrace (Barclay 1993). The task of removing the metallic debris and transporting it to a U.S. EPA approved dump site 3 miles from the atoll required several expeditions to the Refuge due to the difficulties involved in working in the intertidal zone and removing large pieces of metal from a remote atoll **(Figures 8-10) (Table 1)**.

In 1993 the ship owner's insurance company hired a tug boat which was able to remove the bow and several other pieces of the ship (~116 tons) and towed them out to deep water for disposal. While there was concern that the bow may not have been deposited far enough from the atoll to prevent it from affecting the atoll, a 2005 Hawaii Underwater Research Laboratory (HURL) expedition with a submersible confirmed that the bow was indeed deposited deep enough that it was no longer a concern (Finney 2005). In 1999 and 2000 FWS conducted emergency restoration actions (debris removal) and was able to remove another ~107 tons. In 2004 and 2005, hurricanes washed up ~25 more tons of metallic debris from the fore reef to the reef crest. Debris removal operations continued with expeditions in 2004, 2005, 2007. A follow up debris removal operation was completed in 2010 (**Table 1**).

In February 2012, scuba surveys of the fore-reef and walks on the reef crest revealed no visible pieces of metal. Removal of the debris was a monumental accomplishment which has started Rose Atoll down the path to reef ecosystem recovery. The main restoration actions were completed in 2007, and FWS has subsequently initiated the 10 years of monitoring (2007 – 2017) as specified in the Restoration Plan.

Dissolved Iron Monitoring

Iron surveys were completed in 1997, 1998, 2002, 2004, 2005, and 2010. These surveys focused on SW fore-reef transects near the site of the wreckage, and in some years also included other fore-reef arms as well as central and back reef areas (**Table 2**).

Burgett (2003) states that 1998 iron sampling showed a very clear "plume" pattern peaking at the wreckage site (**Figure 11**). In 2002, concentrations of iron in water near the wreck were still 5- to 10- times higher than background levels. However, from 1998 to 2002 peak iron concentrations in the plume decreased by half, indicating that debris removal was reducing iron levels. While iron levels in the plum declined in 2005 and 2010, peak iron levels nearest the wreck site remained similar to 2002, indicating that iron inputs from the shipwreck have persisted but at a much reduced level (Burgett unpublished) (**Figures 12-13**).

All the readily-recoverable iron has been removed, but some unknown amount remains tucked away in cracks and crevasses, and continues to dissolve. Smaller pieces below the detection limit for removal should dissolve relatively quickly in the marine environment, and should result in a progressive decline in dissolved iron over the next decade. This would not have happened without the removal of the large pieces. Because iron levels maintain the invasive species bloom caused by the spill, FWS will continue iron monitoring in order to compare changes in the biological community with changes in iron levels. We suspect that removal of the final 1 ton of visible debris in 2010 will lead to a reduction in iron levels at the peak of the plum.

Additionally, CCA has increased and cyanobacteria decreased at the survey site closest to the wreck between 2006 and 2012 (Vargas-Angel pers. comm.), supporting metal debris removal as the preferred restoration technique.

Figure 8. Cutting a large piece of debris into smaller sizes for removal from the reef. (J. Maragos)

Figure 9. Divers lifting debris from the fore reef using lift bags. Before this debris could be removed it had to be cut into manageable pieces with an underwater cutting torch.

Figure 10. Transporting debris to EPA approved disposal area 3 nautical miles from the Refuge. (J. Maragos)

Table 1. Timeline and location of metal and other debris removal at Rose Atoll NWR.

Date	Tons of Metal Removed	Tons of non-metalic debris removed	Where	Notes
Dec 1993	116		Reef flat	Bow (76 tons), shetter deck (2 tons), misc (38 tons) Removed by the tug boat hired by the insurance company.
Dec 1993		??	Reef flat	Line, netting, other debris.
July 1999	75		reef flat	Emergency Restoration Action
July 1999	2		Lagoon	Emergency Restoration Action
April 2000	30		reef slope	Emergency Restoration Action
Jan 2004				25 tons of metalic debris cast up on reef crest during a huricane.
July 2004	10		Lagoon	
July 2004	15		Reef Flat	
July 2004		10	Lagoon	Line, netting, other debris.
Jan 2005		5	Lagoon	Line, netting, other debris.
Jan 2005	20		reef flat	
Jun 2005	40		Reef Slope	
July 2005				HURL mission shows bow section gone
Jan 2007	2		Reef slope	
Sept 2010	1		reef flat	
Total	**311**	**>15**		

Table 2. Timeline and location of dissolved iron sampling at Rose Atoll NWR and status of data analyses (Burgett unpublished).

Date	Iron data collection location	Analysis
Jan 1997	Fore-reef and one cross-reef transect	Analyzed and plotted.
Aug 1998	Fore, mid, back-reef	Analyzed and plotted.
Feb 2002	Fore-reef only	Analyzed and plotted.
July 2004	SW fore-reef, one fore-reef station at each of the other 3 arms	Analyzed and plotted.
July 2005	SW fore-reef, central SW mid and back reef.	Analyzed and plotted.
Sept 2010	SW fore-reef, central SW mid and back reef, higher density to characterize plume.	No analyses to date.

Figure 11: Concentration of total dissolved Iron (Fe) in water flowing over the southwest arm of Rose Atoll, February 1998. In this graph the X axis is the seaward edge of the atoll's southwest arm, and the Y axis is the width of the reef flat, extending from the outer seaward edge to the inner lagoon edge. This "virtual view" is therefore from the west (Burgett, 2003).

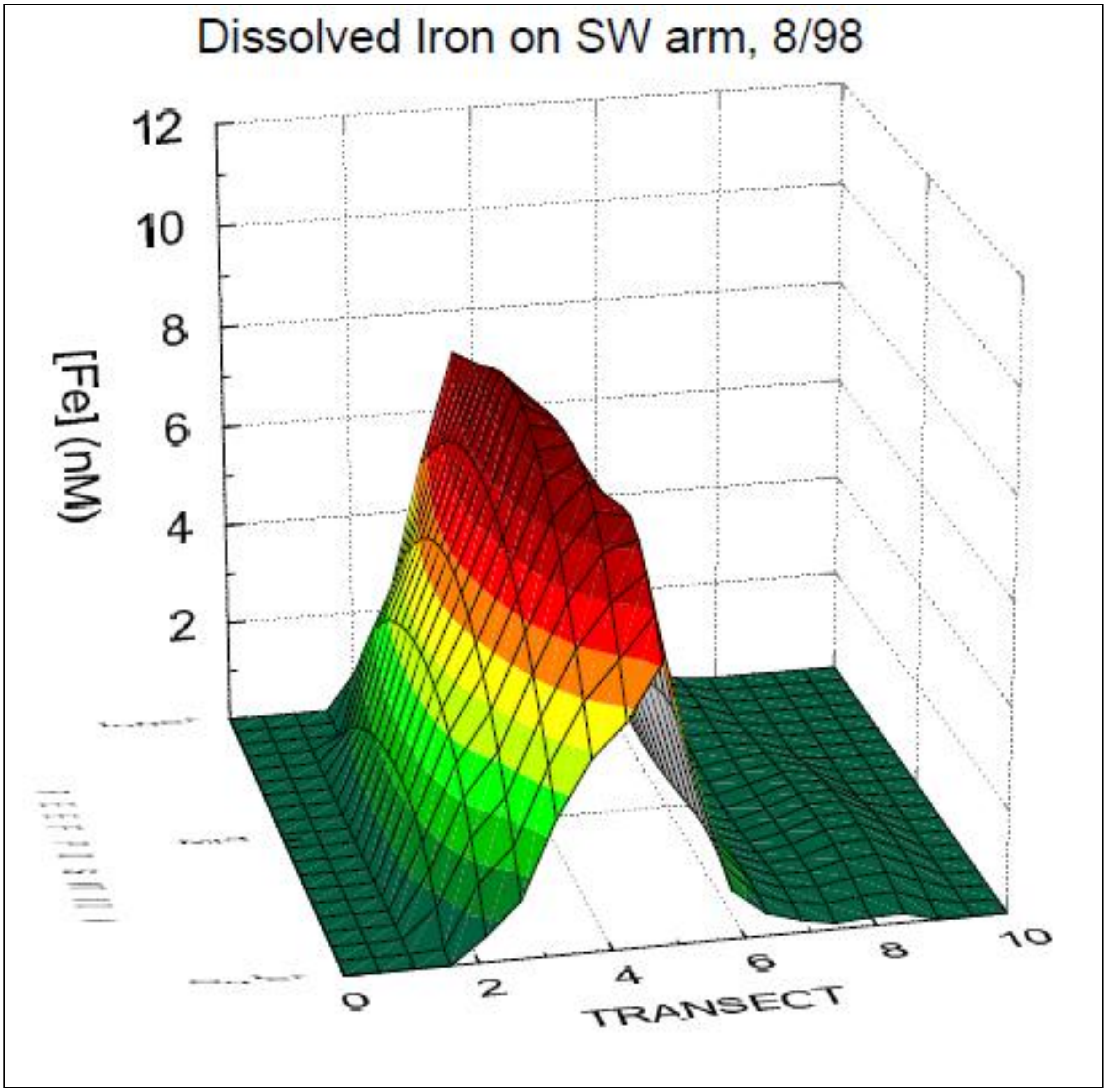


Figure 12: Concentration of total dissolved Iron (Fe) at the fore-reef edge of the southwest arm of Rose Atoll, before (1998) and during (2002) debris removal (Burgett, 2003).

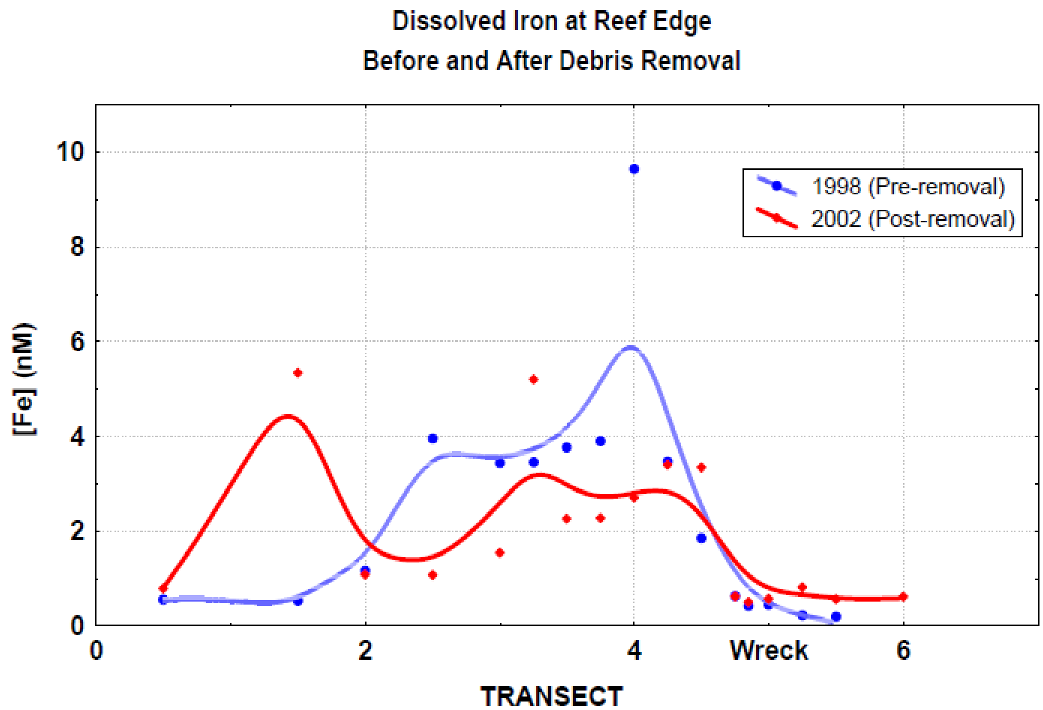
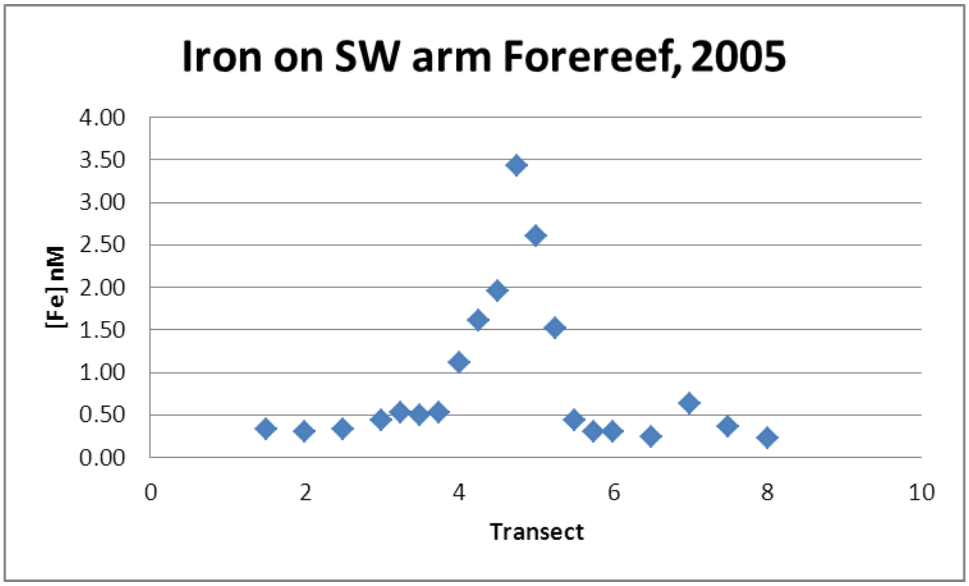
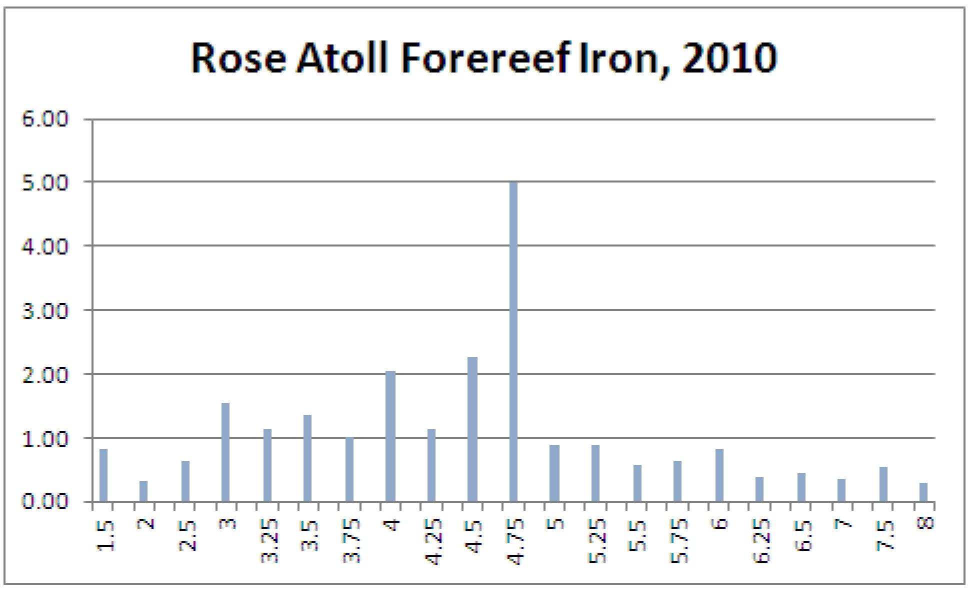


Figure 13: Concentration of total dissolved Iron (Fe) at the fore-reef edge of the southwest arm of Rose Atoll in 2005 and 2010 (Burgett unpublished data).





Algae and Cyanobacteria

CCA prospers in low iron environments such as Rose Atoll, and as the dominant reef building organisms they are critical to the integrity of the ecosystem. Within three weeks of the oil spill, a large area of the normally pink CCA had bleached, suggesting that a massive die off had occurred as a result of the spill (Molina 1994). This coincided with a bloom of invasive cyanobacteria and articulated coralline algae (*Jania spp.*), a red alga that forms tufts rather than crusts and does not build solid reef. Within weeks of the oil spill, these invasive species had become well established along 700 m of SW arm of Rose Atoll with the densest patches close to the spill site (**Figures 1-3**). Within 2 months the invasive species dominated area had grown to 1000 m along the SW arm. On the arms which were not directly impacted by the diesel spill, CCA appeared to be healthy, with cyanobacteria and articulated coralline algae absent **(Figures 14-15)**.

The importance of removing iron debris for the recovery of CCA became apparent after observing the “rebar effect” at study sites. Steel rebar posts driven into the reef to mark survey sites created a wake of cyanobacteria and dead CCA in the flow line behind these posts **(Figure 16)** (Burgett 2003). This suggested that the suppression of CCA and dominance of invasive species on the SW arm closest to the spill site was due to the iron rich environment. Ship wrecks in low iron regions have led to reef system collapses and the development of “black reefs” throughout the tropical Pacific (Kelly et al. 2011).

Quantitative surveys of the algal community on the reef crest conducted between 1995 and 2010 **(Table 3)**, documented that the most common invasive species were *Jania adherens*, *Oscillatoria* spp., *Lingbya* spp., and *Codium* spp., and that cyanobacteria and turf algae were prominent near the spill site and uncommon on the northwest or southeast arms (Burgett 2002) **(Figure 17)**. Sixty permanent algal sampling stations have been established and monitored repeatedly since 1995, providing data for detailed quantitative analysis of algal community change across the atoll’s reef flat **(Figure 18)**.

Quantitative algal surveys were conducted on the outside reef slope by DMWR in 1994, 1995 and 1996 (Green et al. 1997; Schroeder et al. 2008). The reef slope showed a die off of CCA and a bloom of invasive algae near the spill site. Cover of invasive algae was twice as high at the impact site than at any other site on the SW arm, and there were no invasive algae on the NW arm. Dead CCA was the dominant substrate at the spill site (36%), and live CCA was only 4%. At all other sites live CCA cover ranged from 20-40% **(Figure 19)** (Green et al. 1997; Schroeder et al. 2008).

Beginning in 2002, the National Oceanic and Atmospheric Administrations (NOAA) Coral Reef Ecosystem Division (CRED) began monitoring exercises at Rose Atoll on a 2 year cycle. In 2002, they found invasive algae were an order of magnitude higher at the spill site (40%) than at adjacent stations **(Figure 19)**. In 2004, invasive algae remained high at the spill site (40%) and had increased at the other SW arm stations, and by 2006 invasive algae had spread along the SW arm and were 30% for SW arm sites 1 km from the wreck. More recently, CRED has reported that cyanobacteria near the wreck site declined from 40% in 2002 to 10% in 2010 (PIFSC 2011), demonstrating that the removal of debris is helping to restore the site. And while 2012 data has not been analyzed, invasive species near the spill site are clearly decreasing (**Figures 20-21**)

Based on FWS February and April 2012 visual inspections, the lagoon, reef crest and fore reef are responding differently to the removal of metallic debris. These environments differ greatly in the amount of flushing, the amount of wave energy, the fish and other animals capable of controlling cyanobacteria, and in many other respects. Presently, the fore reef is showing clear signs of improvement (PIFSC 2011) (**Figure 21)** which was also recognized by CRED researchers on their

2012 cruise (Vargas-Angel pers. comm. 2012). Improvement on the reef crest is noticeable, but not to the level of the fore reef. The size of the algae bloom has decreased (**Figures 1 and 2**), but there is still invasive algae **(Figure 22)**. Data from 2004, 2005 and 2010 will need to be analyzed to determine if the CCA is returning to dominance on the reef crest. The pinnacles in the lagoon nearest the spill site remain dominated by cyanobacteria, and will likely take many years to show clear signs of recovery (**Figure 23)**.

In 2010, FWS experimented with removing cyanobacteria from pinnacles in the lagoon using suction pumps, wire brushes, putty knives, and by hand (Ray-Culp 2010). The work was described as “labor intensive and endless” (Burgett pers. comm.), but was a valuable attempt at curbing further spread of the cyanobacteria throughout the atoll. However, as long as the environment in the lagoon is conducive to the growth of cyanobacteria, efforts to remove it will be very similar to mowing a lawn, and the cyanobacteria will just grow right back. This restoration action was described in the Restoration Plan and was included as part of the Contingency that was approved in the Trustees subsequent Amendment to Natural Resource Damage Claim for Rose Atoll National Wildlife Refuge. FWS will continue to assess the need to conduct additional restoration actions utilizing this method as a contingency to restoring a healthy coral ecosystem at Rose Atoll.

Figure 14. Photo of a healthy reef on the SE arm showing the dominant pink crustos coralline algae (Photo by G Sanders)

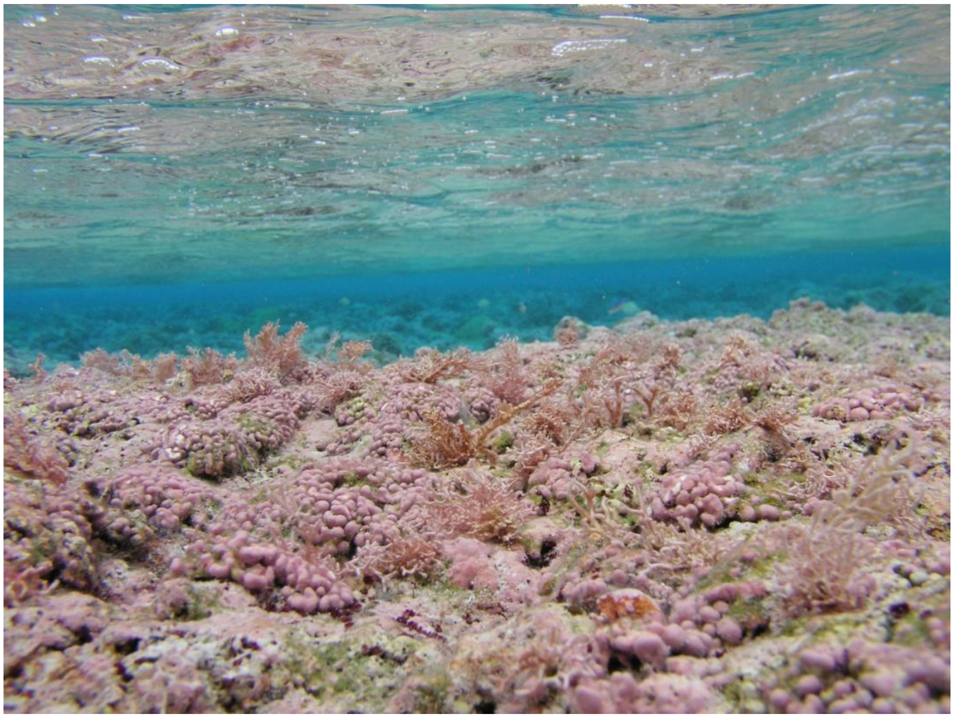


Figure 15. Photo of a the unhealthy reef on the SW arm near the spill site, showing the dominance of cyanobacteria. (J. Burgett)

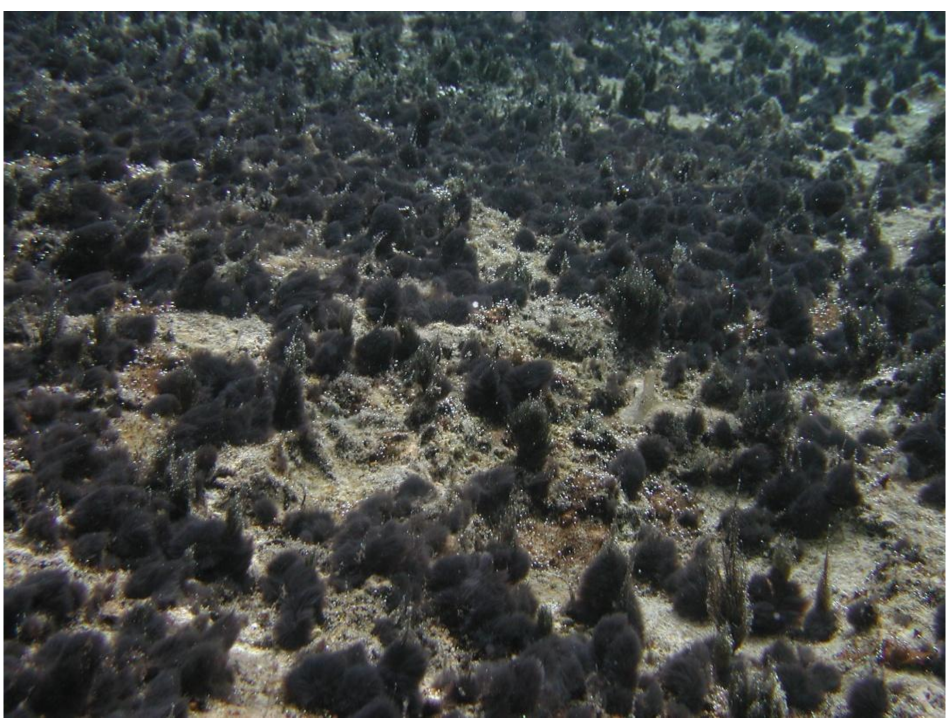


Figure 16. The “rebar effect”, showing cyanobacteria growing on the downstream side of rebar posts initially used to mark study sites, alerted managers that increased iron levels were likely maintaining the cyanobacteria bloom. These stakes were changed to stainless steel.

Table 3. Timeline and location of algae data collected at Rose Atoll NWR and status of data analyses (Burgett unpublished).

Date	Year	Algae data collection location	Analyses
Aug 1995	1995	SW and SE arm	Analyzed and plotted
July 1996	1996	all arms	Analyzed and plotted
Jan 1997	1997	qualitative observations	No data taken
Aug 1998	1998	all arms	Analyzed and plotted
Feb 2002	2002	all arms	Analyzed and plotted
May 2004	2004	qualitative observations	No data taken
July 2004	2004	all arms	No analyses to date
July 2005	2005	all arms	No analyses to date
Sept 2010	2010	all arms	No analyses to date

Figure 17: Iron concentrations, cover of CCA and opportunistic algal species (cyanobacteria and *Jania*) on the outer reef flat three years after the ship grounding (Green et al.1997).

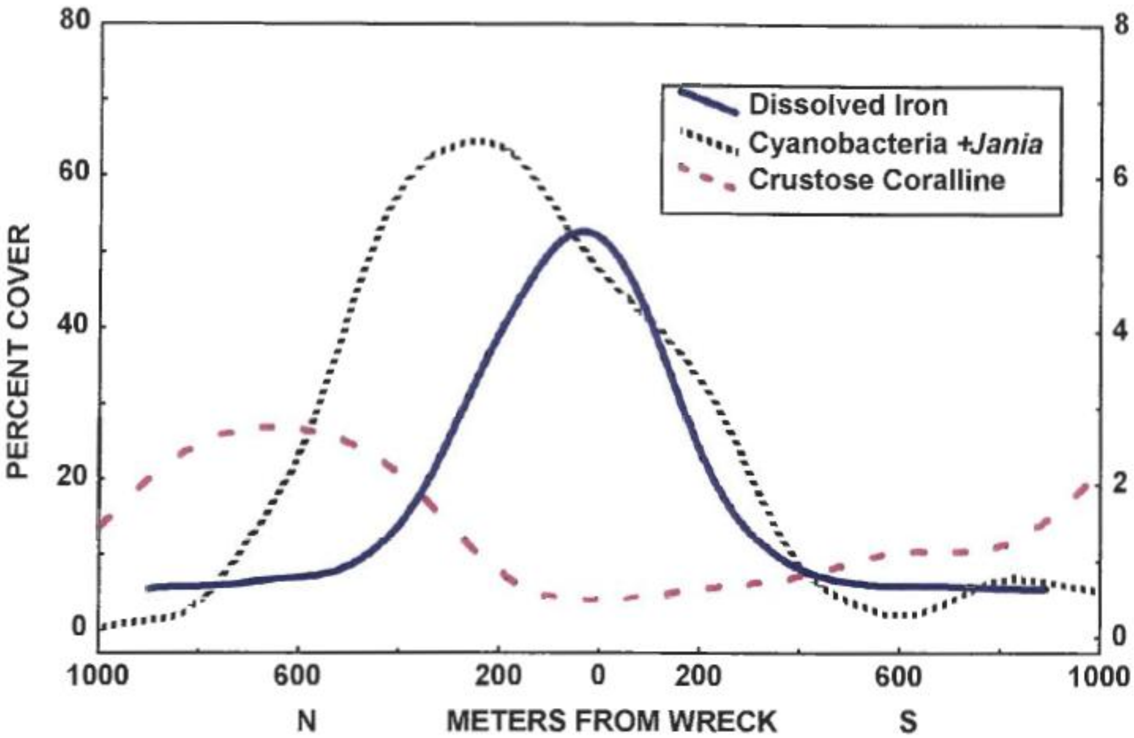


Figure 18: Aerial photograph of Rose Atoll showing locations of **reef crest** algal survey stations. Transect 0 is at the upper (northwest) end of the southwest arm, and transect 10 is at the bottom (southeast) end. In this image, dark bands of cyanobacteria can be seen extending across the reef flat from the seaward edge, especially just north of the wreck site (transect 5). Imagery is from GeoEye 2011.

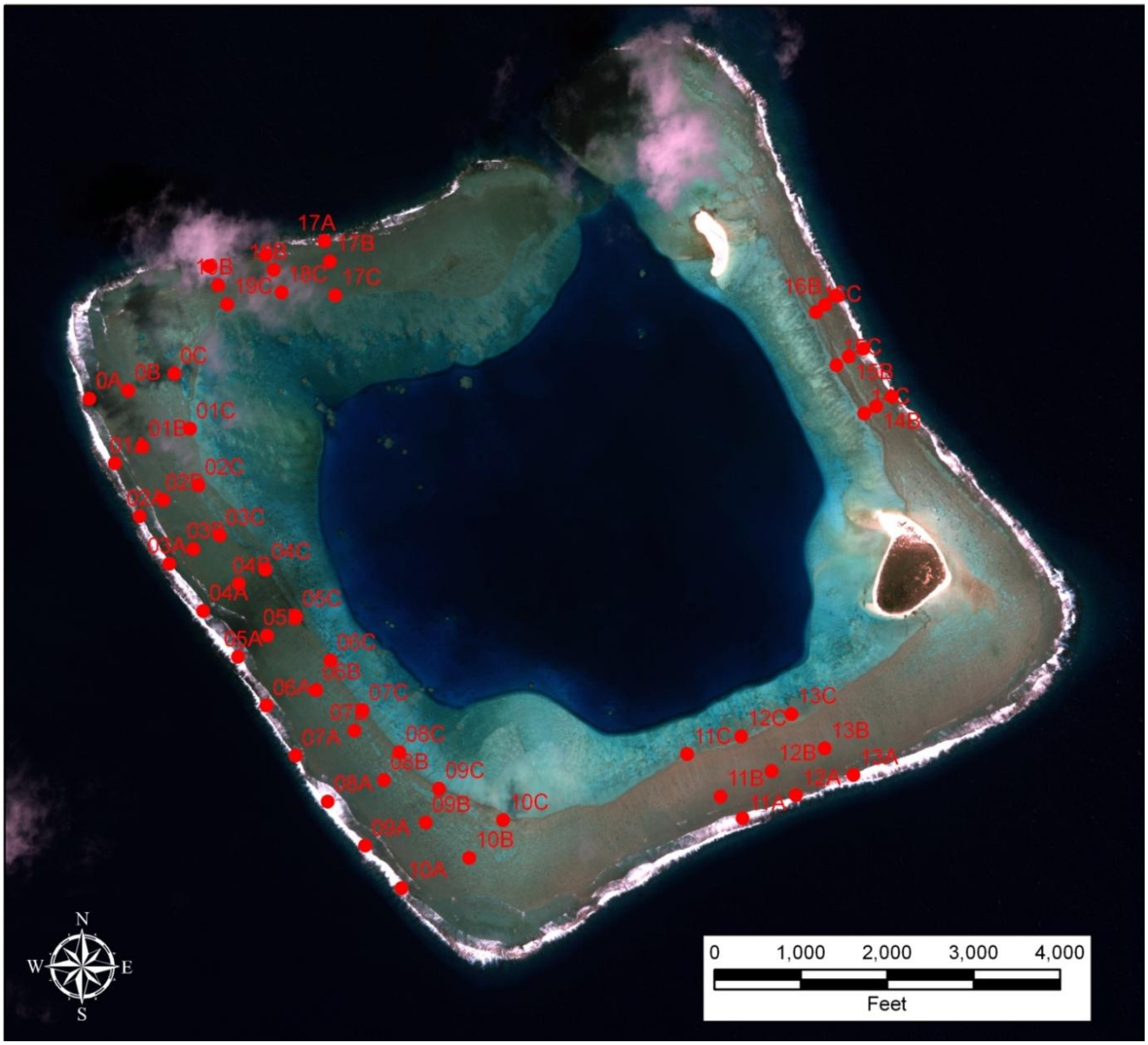


Figure 19. Mean (+ SE) percent cover of turf algae/cyanobacteria among outer reef slope stations by year (1995–2006) (* = site of 1993 grounding [SW1 in 1995 and Stn-7 in 2002–2006]; nd = no data for that station-year). In 1995, station SW1 had significantly higher cover of opportunistic algae (turf and cyanobacteria) than the other sites (Wilcoxon Kruskal Wallis one-way ANOVA; $P < 0.05$). In 2002–2006, significant differences also occurred among stations, with the least square means of the wreck site about twice as high as the other stations (two-way ANOVA; $P < 0.0001$) (from Schroeder et al. 2008).

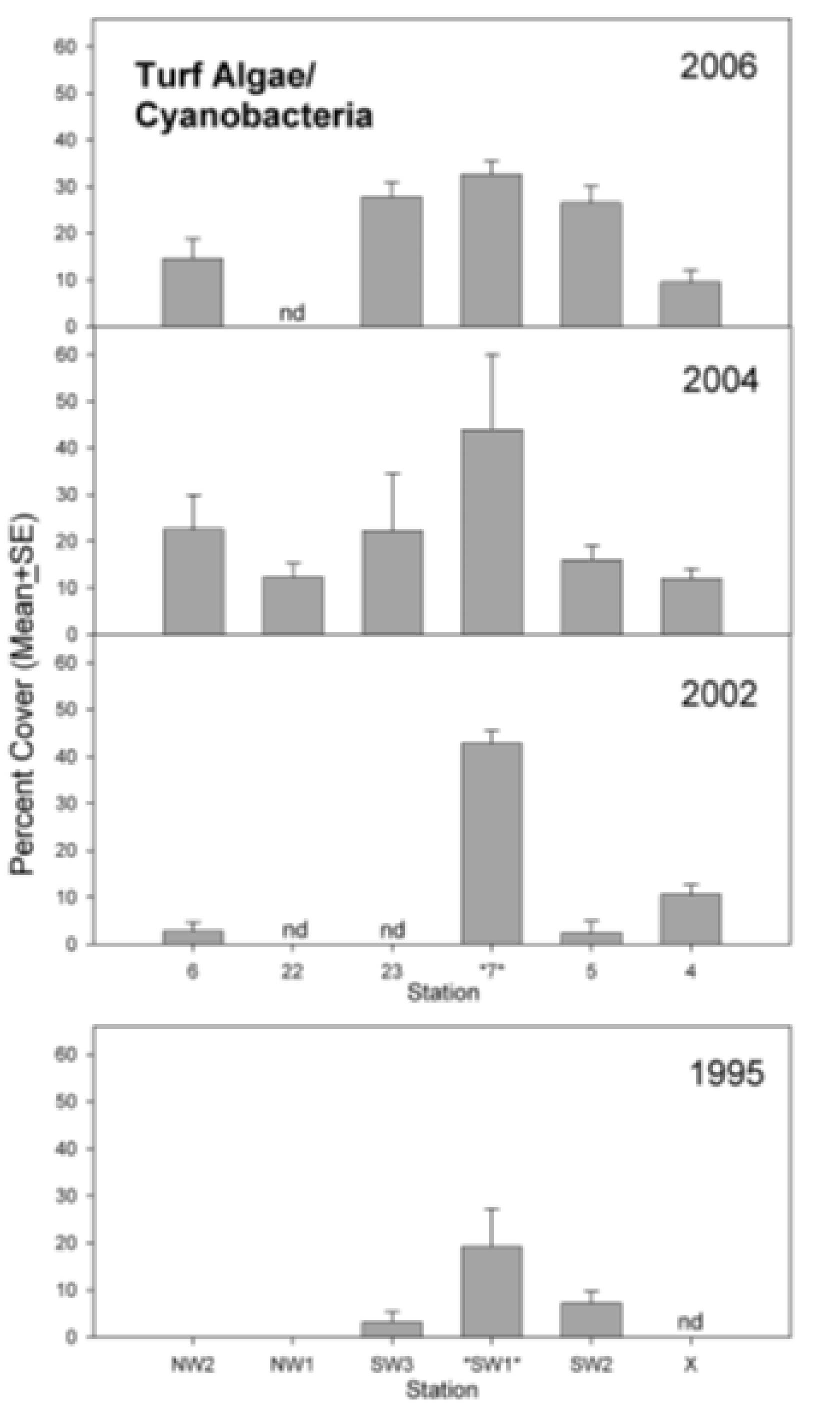


Figure 20. Typical photo along the fore reef coral transect nearest the ship wreck site in **2006**. Cyanobacteria is prominent and covering many corals. (CRED)

Figure 21. Typical photo along the fore reef coral transect nearest the ship wreck site in **2012.** Cyanobacteria cover is greatly reduced and corals are colonizing the area. (CRED)

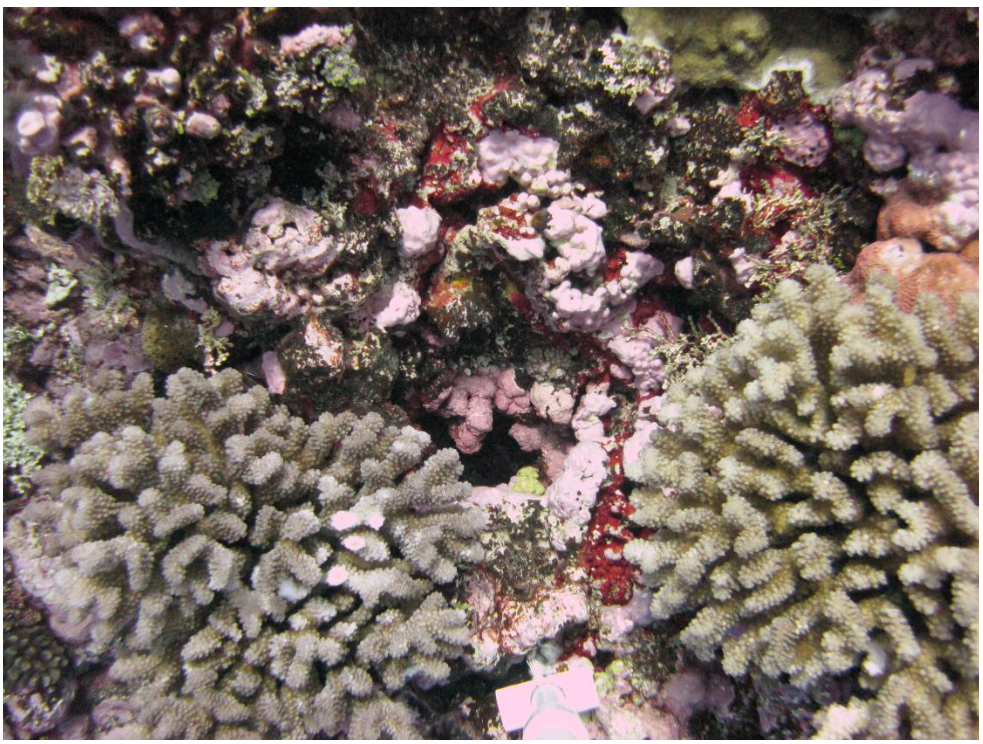
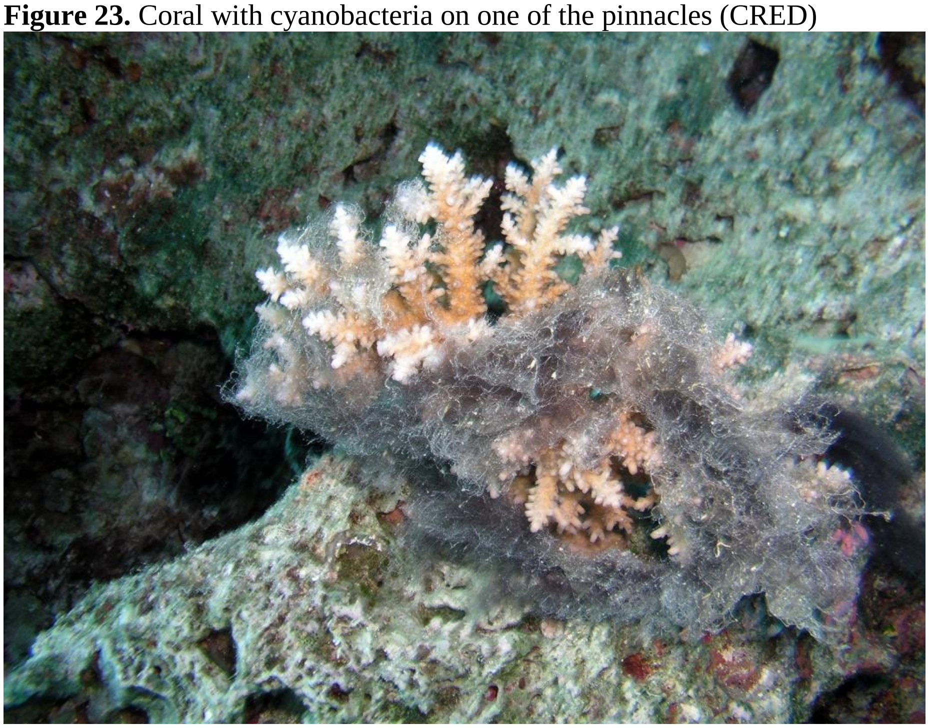


Figure 22 Typical photo along the reef crest near the ship wreck in 2012. While there is still some cyanobacteria cover, it is greatly reduced from previous years and CCA is recovering. (T. Clark)

Figure 23. Coral with cyanobacteria on one of the pinnacles (CRED)



Echinoderms

Boring sea urchins (*Echinometra oblonga* and *E. mathaei*) were surveyed on the outer reef flat two weeks after the spill, and also in 1995 and 1996 (**Table 4**). Density of both species were quantified via quadrat surveys along a transect on the outer reef flat on the southwest arm, extending 200-220 m north and south of the spill site (Molina 1994). Surveys in later years also included the three other arms of the atoll.

The 1993 surveys showed scouring along a 10 m section of the transect and urchin holes filled with sediment (USFWS & DMWR 1997). An additional 40 m on either side of this section was scoured, but the urchin holes remained in-tact. No urchins were recorded 60 m south and 90 m north of the spill site and urchin density generally increased with distance from the spill site. This survey indicated that many boring urchins were killed by the oil spill along the seaward portion of the outer reef flat on the southwest arm (Molina 1994). Surveys in 1995 and 1996 indicated continued decline of boring urchins on the outer reef flat of the southwest arm, and a lower density of boring urchins than on any of the other three arms. (**Figure 24**)

Additional surveys of boring urchins were conducted by USFWS in 1998, 2004, 2005, 2010 **(Table 4).** Data from 1998 have been plotted and analyzed, but were not available for this report. Data collected from 2004-2010 remain to be analyzed, and FWS plans to hire a 3rd party to analyze them in the near future.

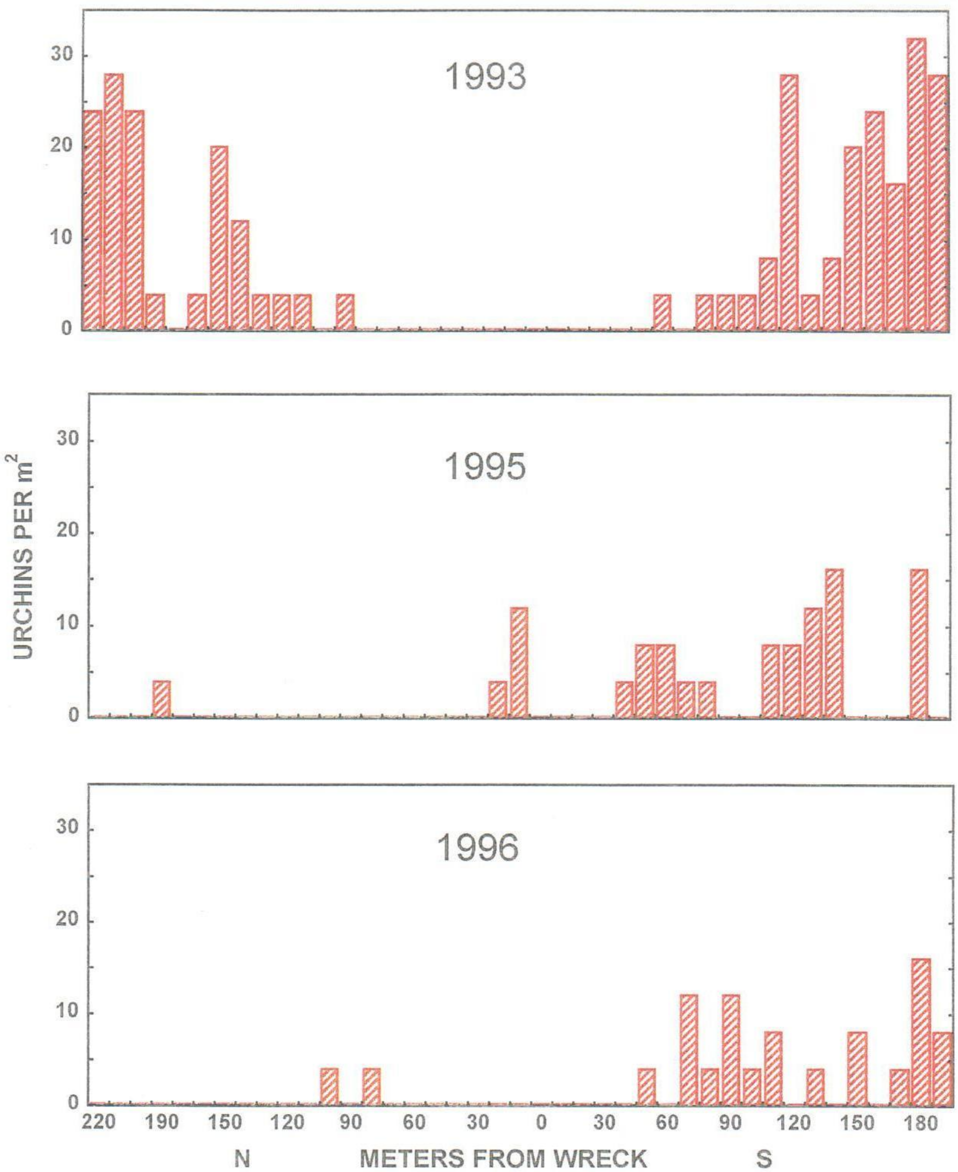
In contrast to boring urchins, surveys of the herbivorous urchin (*Diadema c.f. savignyi*) on the southwest and southeast arms of Rose Atoll in 1993 indicated that this urchin increased in abundance at the wreck site. These urchins were much more abundant on the southwest arm nearest the wreck site than on the southeast arm. Hypotheses for this increase included natural variation or increased abundance of algal food sources (Green et al. 1997).

Surveys of sea cucumbers (*Holothurians*) were also conducted on the southwest and southeast arms of Rose Atoll in 1995 and on all arms of the atoll in 1996. Sea cucumber abundance was highest on the southeast arm and much lower on the other three arms. The southwest arm had one of the lowest densities of Holothurians on the atoll (Green et al. 1997). Additional surveys of sea cucumbers were conducted in 1998, 2004, and 2005 **(Table 4).** Data from 1998 have been plotted and analyzed, but were not available for this report. Data collected from 2004-2010 remain to be analyzed.

Table 4. Data collection and state of analysis for urchins and sea cucumbers at Rose Atoll NWR.

Date	Urchins	Sea Cucumbers	Analyses
July 1996	All Arms	All Arms	Analyzed
Aug 1998	All Arms	All Arms	Analyzed
July 2004	All Arms	All Arms	Not Analyzed
July 2005	All Arms	All Arms	Not Analyzed
Aug 2010	All Arms	no	Not Analyzed

Figure 24. Abundance of boring sea urchins (*Echinometra* spp.) on the reef flat margin of the SW arm 2 weeks, 2 years, and 3 years after the ship wreck and fuel spill.



Coral Monitoring

Knowledge of coral reef communities at Rose Atoll has grown substantially as a result of monitoring to assess effects of the 1993 oil spill. Prior to 1993, relatively little of the literature concerning Rose Atoll dealt with its corals (Kenyon et al. 2010). Rodgers et al. (1993) found that fewer than 20 of 297 citations pertaining to Rose Atoll related to corals or coral reef structure. As a consequence, only 11 coral species from 9 genera were recorded in the literature for Rose Atoll between 1924 and 1988. In contrast, Kenyon et al. (2010) found that intensified inventory and monitoring efforts from 1994 to 2007 documented 143 species of corals. In addition to increasing basic understanding of coral composition at Rose, these surveys have documented changes in the coral community resulting from the ship grounding, associated oil and chemical spill and restoration efforts.

Table 5 provides a timeline detailing coral inventory and monitoring efforts at Rose Atoll to date. Initial emergency damage assessments of the reef noted deterioration at the site of the vessel grounding on the SW fore reef within a matter of weeks after the spill (Maragos et al. 2005) and direct physical damage to the reef including shearing, pulverizing and scarring across approximately 1200 m^2 of the steep spur-and-groove zone on the southwest fore-reef (Molina 1995; Green et al. 1997). All organisms underlying the shipwreck were killed and dead coral were reported in the areas exposed to the spill (500,000 m^2) (USFWS 1997).

Following initial damage assessments, coral monitoring surveys were initiated by USFWS and DMWR in 1994 to characterize impacts of the spill (Maragos 1994; Green 1996; Green et al. 1997). These initial monitoring efforts focused on the area most heavily impacted by the shipwreck and release of oil (Kenyon et al. 2010). The surveys documented deterioration of corals updrift and downdrift of the vessel and into the reef flat and lagoon (Maragos 1994). Oil-related injuries were documented to include dead or injured coral along the outer reef slope and reef flat, and the slope, floor and pinnacles of the lagoon (Maragos 1994; USFWS 1997). Molina (1995) found that six months after the wreck, corals were stressed due to the algal infestation on lagoon pinnacles in the NW corner of the lagoon. In 1997, USFWS documented several pinnacles in the lagoon that were largely devoid of any living coral colonies and several of those pinnacles continued to be devoid of any living coral colonies as of April 2000 (USFWS 2001).

Early post-wreck surveys also enabled the documentation of an extensive coral bleaching event unrelated to the ship grounding in 1994 (Maragos 1994). Kenyon et al. (2010) state that “although the bleaching event was likely a regional phenomenon rather the result of local perturbations caused by the ship grounding and chemical spill, bleaching was nonetheless most pronounced along the southwest fore-reef, and its severity increased slightly when moving towards the wreckage (Maragos 1994), a sign that stress to corals from the oil spill may have contributed to the severity of the event.”

From 1999 to 2007, twenty (20) permanently marked transects were established to monitor coral (Maragos 2008) **(Figure 25) (Table 6**). These sites have been resurveyed by USFWS through 2012. Data include visual estimates of percent coral cover and size class, genera and species identification, and calculations of generic richness. The surveys provide a spatially explicit record of coral genera and species decline and recovery post-spill.

Complimentary to the surveys conducted by USFWS and DMWR, CRED initiated spatial assessments of the composition and condition of shallow benthic habitats at Rose Atoll in 2002 as part of a larger effort to assess and monitor coral reef ecosystems in the U.S. Pacific Islands (Brainard et al. 2008). These surveys have continued bi-annually from 2002 to present. Related to this effort, researchers conducted towed-diver surveys over 33 km of benthic habitat at Rose Atoll in

2002 and 45 km in 2004; and belt-transect surveys at ten sites on the fore-reef and within the lagoon in 2004, 2006, 2008, 2010 and 2012. Kenyon et al. (2010) described community structure of shallow corals at Rose Atoll, provide an updated coral species list based on surveys conducted 1994 to 2007, and present evidence of coral recovery in the area most heavily impacted by the oil spill.

Results of the collective coral surveys at Rose indicate that, as metal debris removal efforts have continued, coral recovery from the oil spill and bleaching event has occurred and continues. Kenyon et al. (2010) found coral cover along the southwest fore-reef sector, the site of the vessel grounding, to be 3 to 7 times higher than coral cover estimated in 1995 via transects by Green (1996). Similarly, Maragos (unpublished data) records a doubling of coral cover between 2002 and 2006 at a site on the southwest fore-reef, down drift of spill sitek (site 5P) (**Table 6; Figure 26**). These increases on the southwest fore-reef have been dominated by the genus *Pocillopora*. In 2002 and 2004 surveys, *Pocillopora* accounted for the highest proportion of total coral cover in all fore-reef sectors (Kenyon et al. 2010). Because Pocilloporids are coral colonizers, their presence and increasing abundance is indicative of recovery at the wreck site (Vargas-Angel pers. comm.). Kenyon et al. (2010) surmise that the fact that *Pocillopora* are fast growing, and their recorded size on the southwest arm in 2002 and 2004, suggests that the corals settled after the vessel grounding and spill reflect recovery. NMFS (2002) suggests that increases on the SW fore reef section may indicate early states of recovery not only from the spill but also from the bleaching event. Although data from 2012 coral surveys have not been fully analyzed, preliminary results indicate that coral communities continue to recover on the southwest arm, and the recovery corresponds with receding levels of invasive algae and cyanobacteria (Vargas-Angel pers comm).

Recovery has also been observed in other areas of the reef and lagoon. Maragos et al. (2005) noted that, although invasive algae still dominated the reef flats by 2005, brain corals (*Favia, Favites, Montastrea, Goniastrea sp*.) had begun re-colonizing the southwest lagoon reefs updrift of the spill site. Unpublished data provided by Maragos showed almost no coral cover near the north lagoon pass in 1999; by 2012, total coral cover in this area measured 26% dominated by increases in *Montipora* (site 8P) (**Table 6; Figure 26**;). Recoveries in the lagoon and on the reef crest have lagged behind recoveries on the fore reef for a number of potential reasons. Impacts within the reef flat and lagoon occurred after those on the southwest fore-reef as iron and oil has dispersed from the immediate shipwreck site to other areas. Lagoon and reef flat areas also receive less physical wave action and flushing than fore reef areas. Lastly, *Pocilloporids* are particularly fast growing and are more prominent on the fore reef.

Coral recovery at Rose Atoll, however, has not progressed steadily or consistently in all areas. A hurricane that hit the atoll in 2005 directly damaged coral and tossed previously sunken metallic debris from the shipwreck onto the SW fore reef and reef crest (Maragos 2008). Results of surveys at a number of sites depict increases in coral cover up through 2005, but then declines or stunted recoveries after this date (**Figure 27**). These sites include southwest lagoon patch reef and fore-reef transects.

In addition, Maragos et al. (2005) found that, overall, coral recovery was less extensive and diverse on reefs down-drift of the shipwreck through 2004 surveys. In 2004, virtually no brain coral colonization was detected down-drift of the wreck (transect 7P), and from 2004-2007, the overall percentage of coral coverage decreased at down-drift sites closest to the wreck (7P & 23P). Kenyon et al. (2010) suggest that, while Pocilloporid colonies on the southwest fore-reef suggest recovery, the low proportion of Pocilloporid colonies in the less than 10 cm diameter category in 2002 and 2004 surveys suggests reduced recruitment since 1998. The authors surmise that this may be due to the proliferation and increasing spread of invasive algae and cyanobacteria along this sector since the spill and through 2004 surveys (Schroeder et al. 2008). These results suggest that the removal of iron debris and consequent reduction of dissolved iron is important to coral reef recovery.

Maragos (2008) concludes that results of surveys indicate there have been net increases of corals at all permanent sites. “For sites removed from or updrift of the shipwreck, corals have steadily increased in cover, numbers, size, and diversity, except for a minor temporary decline at one site (13P) during the 2005-2006 period following the hurricane. At sites closer to or downdrift of the shipwreck, corals have generally increased, but erratically and with lower diversity and recruitment levels. Overall, the findings look promising for corals, despite two unrelated catastrophes within a year period (1993 ship grounding and 1994 coral bleaching event) (Maragos 2008). Similarly, preliminary results of 2012 coral surveys suggest that coral recovery is progressing at Rose Atoll NWR (Maragos pers. comm.) (Vargas-Angel pers. comm.).

The complete removal of all metallic debris as of 2010 provides the opportunity to assess how coral communities respond to this restoration effort. Continued long-term coral monitoring will be important to document responses of the coral community to changes in levels of iron, cyanobacteria, and invasive algae.

Table 5. Timeline of coral reef assessment, inventory and monitoring at Rose Atoll NWR.

DATE	Activity	Entity/Citation
1839 (Oct)	1st visit by scientists—descriptions of coral reef structure	U.S. Exploring Expedition
1924 to 1988	Early literature collectively documents 11 coral species at Rose and 9 genera	Mayor 1924; Hoffmeister 1925; Setchell 1924; Lamberts 1983; Itano 1988
1993	Initial damage assessment initiated by USFWS and DMWR following October ship grounding at Rose Atoll	
1993	Literature review of 297 citations finds fewer than 20 pertain to corals or reef structure	Rodgers et al. 1993
1994	Monitoring of shipwreck impacts initiated by USFWS	Maragos et al. 1994
1995	Monitoring of shipwreck impacts initiated by DMWR. Five 50-m transects placed at each of 3 sites on the southwest fore reef. Permanent transects established by USFWS on all perimeter reef crests	Green 1996; Green et al. 1997; Maragos 2008
1997	USFWS field surveys	USFWS 2001
1999-2007	20 permanently marked coral and giant clam transects established. Seven transects established in the lagoon in 1999. Thirteen more sites added through 2007.	Maragos 2008
2002-2012	Bi-annual coral surveys by NOAA PIFSC CRED as part of effort to assess U.S. Pacific Island coral reef ecosystems.	Brainard et al. 2008; Kenyon et al. 2010
2005	Resurveying of permanently marked transects by USFWS	Maragos unpublished database
2006	Resurveying of permanently marked transects by USFWS	Maragos unpublished database
2007	Resurveying of permanently marked transects by USFWS	Maragos unpublished database
2010	Updated species list documents 143 species of anthozoan and hydrozoan corals based on collective results of surveys from 1994-2007	Kenyon et al. 2010
2012	Resurveying of permanently marked transects by USFWS	Maragos unpublished database

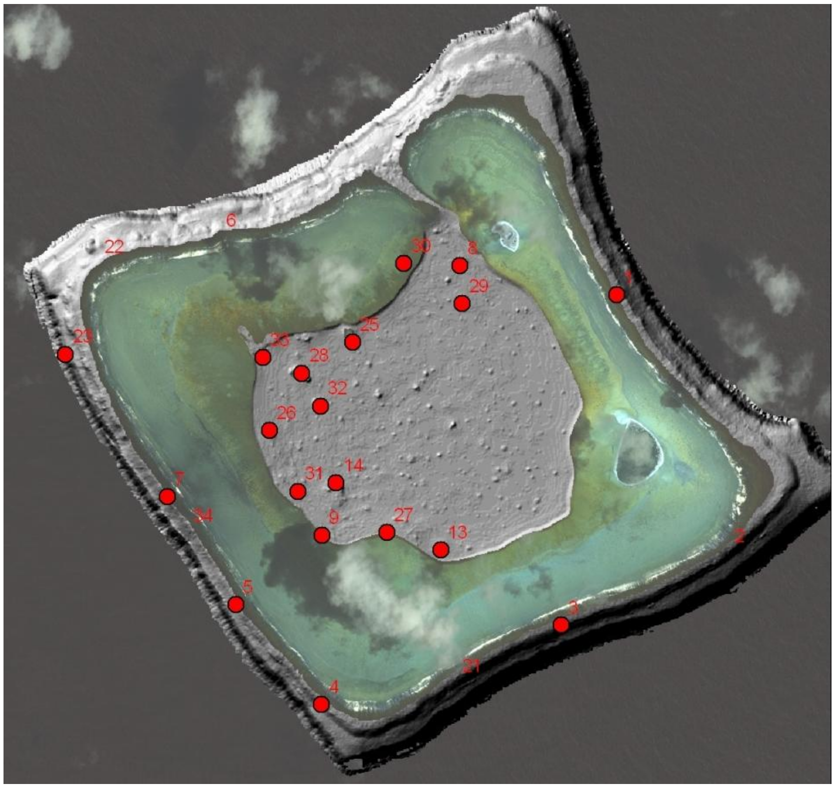


Figure 25. Location of coral transects developed by Maragos to monitor corals following the ship wreck and fuel spill.

Table 6. Percent coral cover at Rose Atoll NWR Transect Survey Sites 1999-2012

Rose Atoll NWR Transect Survey Sites 1994-2012		Percent Coral Cover						
Location	**Transect #**	**1999**	**2002**	**2004**	**2005**	**2006**	**2007**	**2012**
NE fore reef	1P			11		6		
SWS fore reef (down drift of wreck)	4P			10		20		15
SW fore reef (down drift of wreck)	5P		10	13		19		
WSW fore reef (updrift of wreck; this is the site closest to the wreck)	7P		8	11			4	6
W fore reef (updrift of wreck)	23P			16		1		12
N lagoon pass	8P	0.1	0.5	4		6		26
SW lagoon patch reef	9P	3	11	42	28	21	25	6
SW lagoon patch reef	10P	4	5		27	57		35
SW lagoon patch reef	31P				16	10	21	11
SE lagoon patch reef	13P			7	18	16	10	12
WSW lagoon patch reef	26P				17	12	20	17
S lagoon patch reef	27P				12	9	23	12

Figures 26. Changes in coral cover at two sites at Rose Atoll NWR. Site 5P is located on the southwest fore-reef just updrift of the shipwreck. The graph for this site shows steady increases in total coral cover from 2002 to 2006, dominated by Pocillopora spp. Site 8P is a permanent transect located within the lagoon near the channel. Marked coral recovery from 1999 to 2012 is dominated by Montipora spp. (Maragos unpublished)

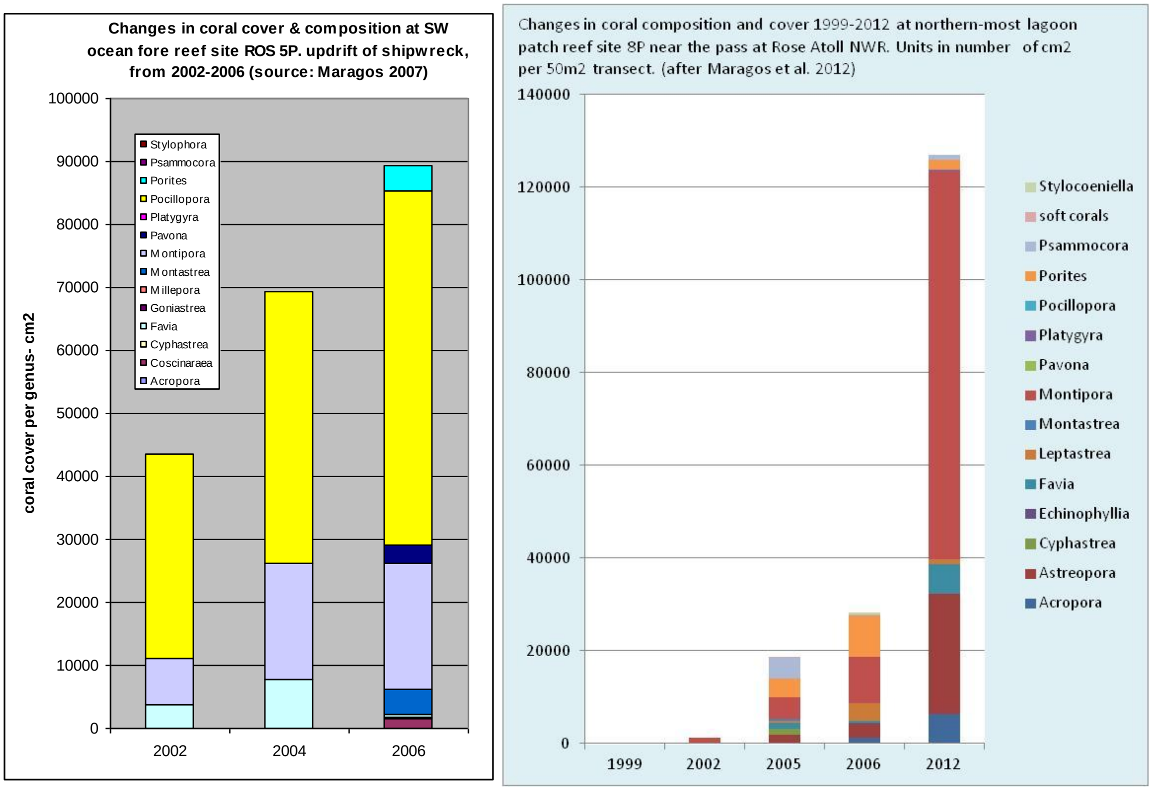
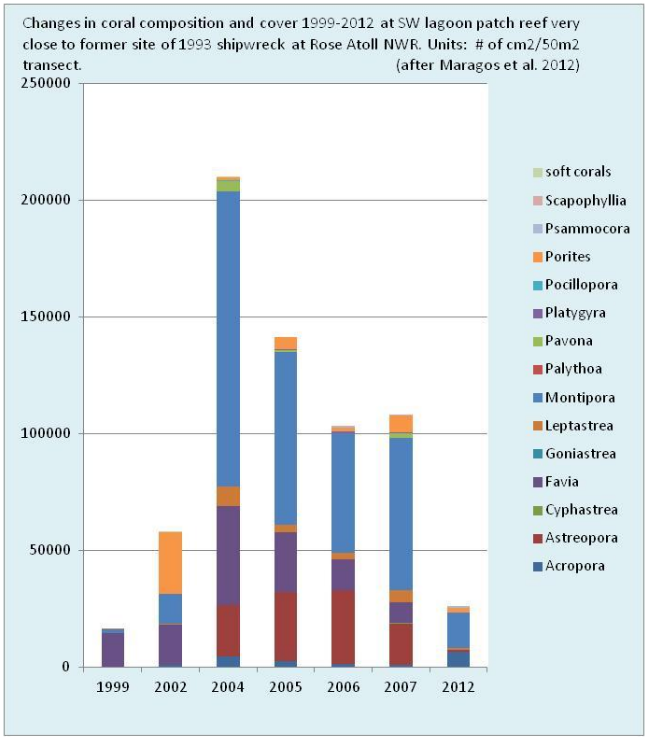
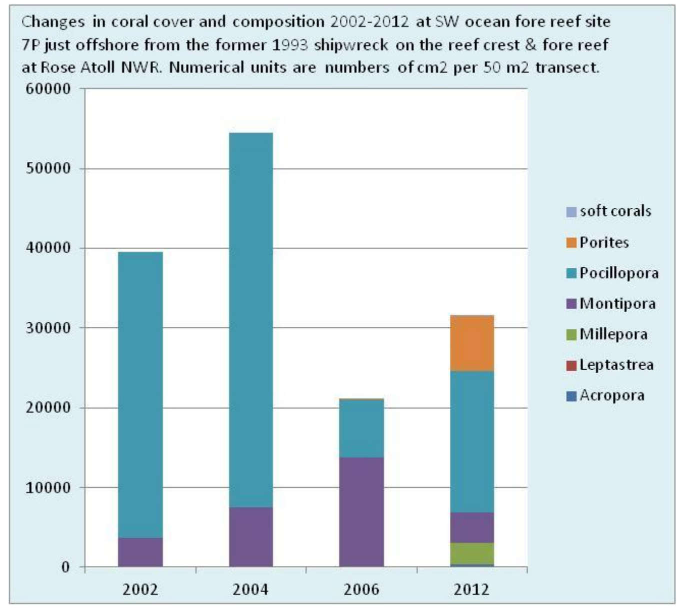
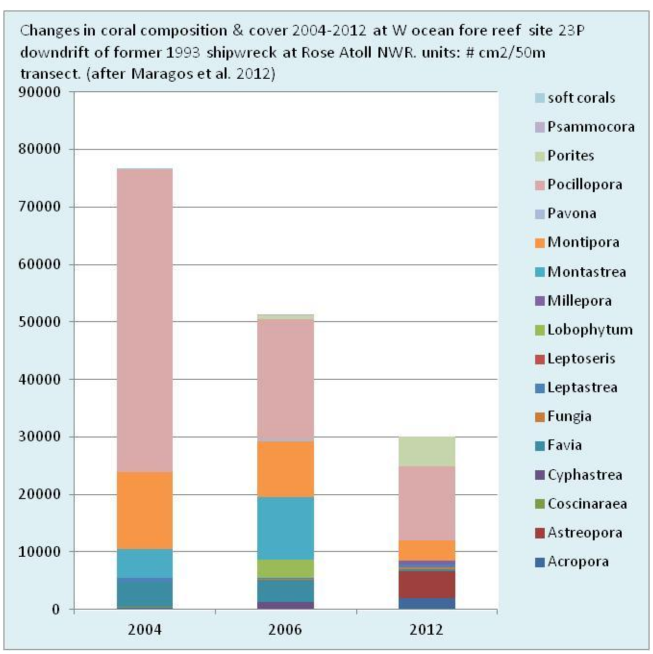
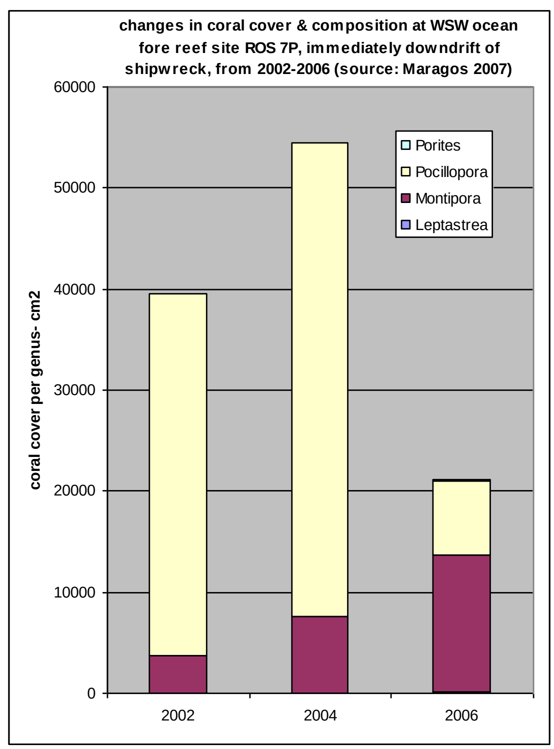


Figure 27. Changes in coral composition on cover at various survey sites at Rose Atoll NWR. These graphs depict declines in coral cover following Hurricane Olaf that passed over Rose Atoll in 2005 (Maragos 2008 & Maragos unpublished).









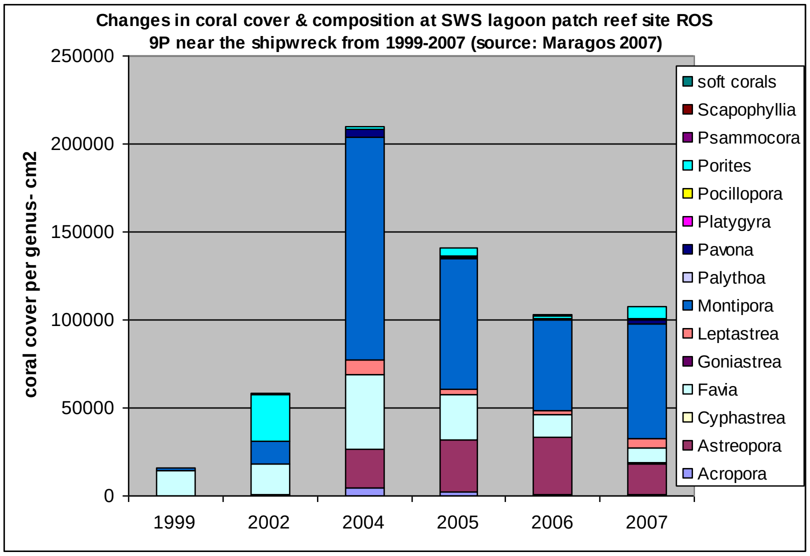


Figure 27. (continued)

Giant Clams (*Tridacna maxima*)

Rose Atoll supports a uniquely abundant population of giant clams (*Tridacna maxima*) within the Samoan Archipelago, accounting for 97% of the total population (Green and Craig 1996; Green and Craig 1999). Rose Atoll is the last remaining coherent refuge for giant clams in American Samoa (Maragos 2008). Initial surveys of the wreck site revealed that large numbers of giant clams appeared to have died as a result of the spill. In order to quantify these effects, giant clams were surveyed along the reef flat on the southwest arm of the atoll two weeks after the spill, and also along the southwest and northwest lagoon terraces (Molina 1994). Approximately 75% mortality of giant clams was observed over 420 m on the lagoon terrace along the southwest side of the atoll. Additionally, dead clams were recorded over a distance of 270 m on the reef flat (from 40 to 310 m northwest of the wreck). In contrast, only 1% of the clams on the northwest arm of the atoll were dead (Molina 1994).

Subsequent observations six months after the grounding revealed that giant clams on the lagoon terrace at the wreck site and on the pinnacles in the northwest corner of the lagoon were covered with a thick growth of cyanobacteria and showed evidence of stress in the form of abnormally thick mucus **(Figure 28)** (Molina 1994; Molina 1995).

DMWR conducted surveys 12 and 18 months after the spill comparing clam densities on the southwest arm with clams throughout the rest of the atoll (Green and Craig 1996). Surveys were conducted along reef flat and lagoon terrace habitats that were most heavily affected by the spill. Clam density and numbers of live, dead, and recently dead clams were measured along transects on each arm of the atoll**.** Similar surveys were conducted on the lagoon pinnacles at three depths on each pinnacle (across the top and at depths of 3 and 10 m) (Green and Craig 1996; Green et al. 1997; Green and Craig 1999). The distribution and abundance of dead clams indicated that there had been an impact on the clam population at the site of the grounding. Sixty-three percent of the dead clams observed (n=24) were recorded on the southwest arm of the atoll (**Figure 30**) (Green and Craig 1996; Green et al. 1997).

The DMWR study concludes that some effects of the spill on the giant clam populations at Rose were still discernible one to two years after the event, but that the overall effects were minimal. Most of the impacts of the spill appear to have been in shallow habitat zones (reef flat and lagoon terrace) and on the outer reef slope, while the most important habitat for clams at Rose Atoll is at the bottom of the pinnacles at depths of 10 m or more. Furthermore, while a large number of clams were found dead shortly after the grounding, this number was small compared to the estimated size of the population on the atoll of at least 27,800 individuals (Green and Craig, 1996; Green et al, 1997, Green and Craig, 1999).

Conclusions were less positive from later surveys of giant clams conducted by USFWS from 1999-2007 along permanent transects. Maragos (2008) concludes that there have been net decreases in clams since 1999 when the surveys commenced, and that more than double the number of clams was observed in 1999 than in 2007. Some gains in clam numbers were noted since 2005 (e.g. **Figure 31**). Maragos (2008) states that the causes of the decline are uncertain. Data on giant clams was recorded in 2012, but has not been analyzed.

Figure 28. Giant clam with cyanobacteria growing on its shell.

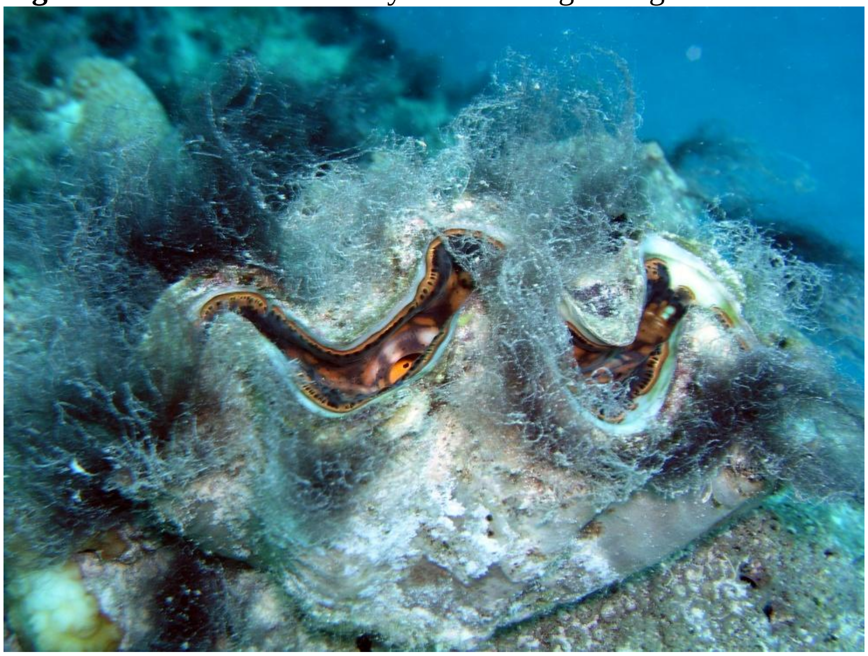


Figure 29. Map of Rose Atoll National Wildlife Refuge showing the location of fish and clam surveys and the position of each habitat type on the reef profile (Green et al. 1997).

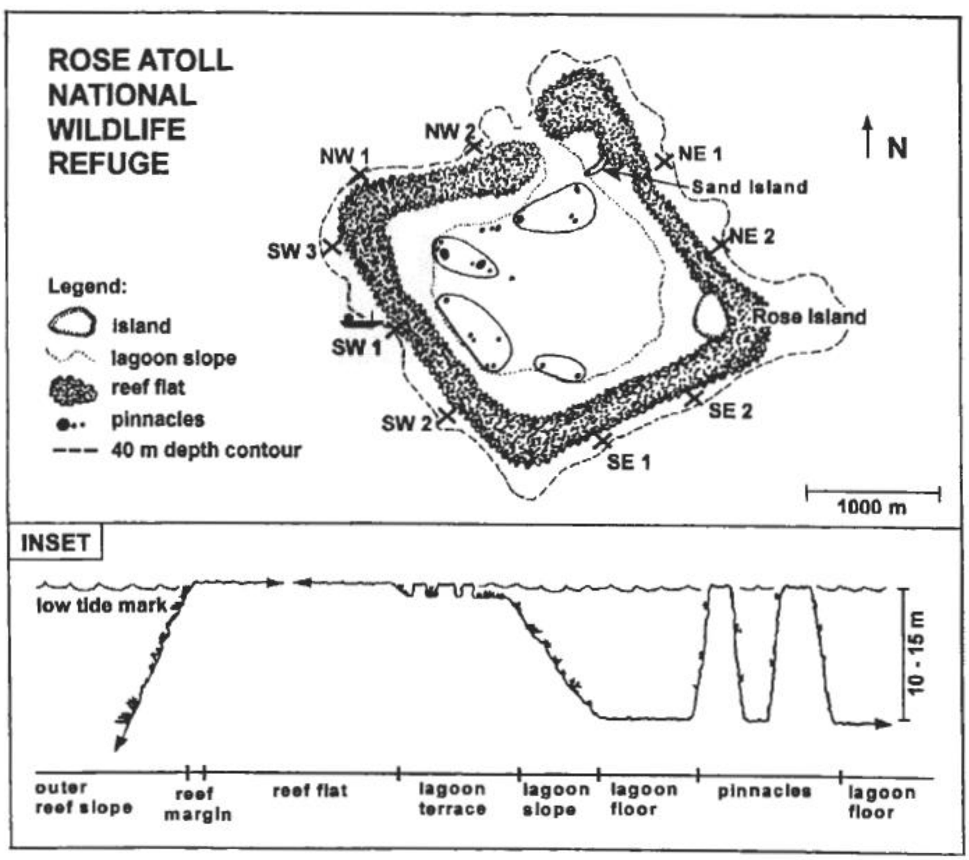


Figure 30. The number of dead giant clams on the lagoon terrace and on pinnacles around Rose Atoll one year after the ship wreck. (Green et al, 1997).

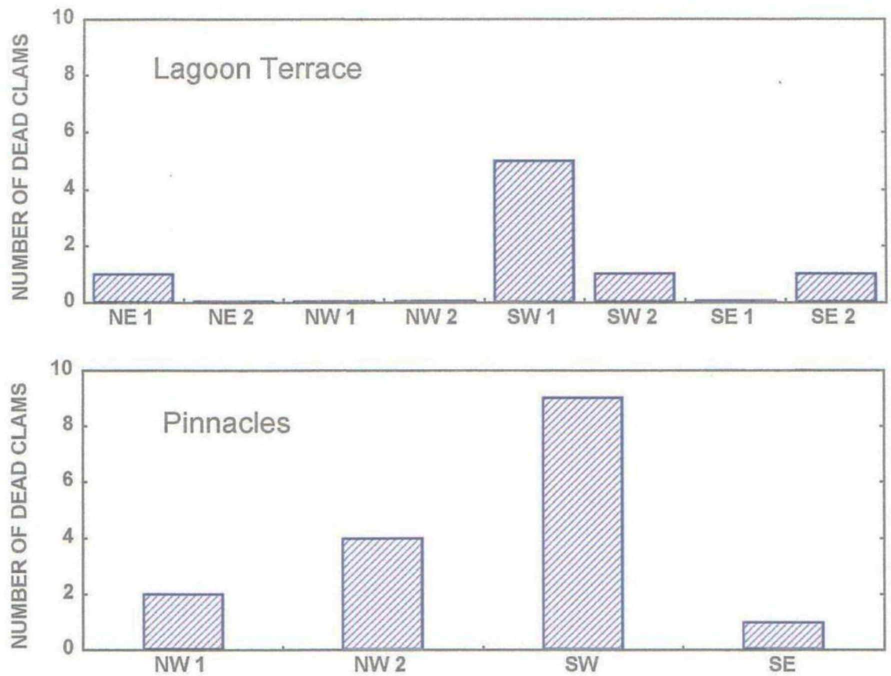
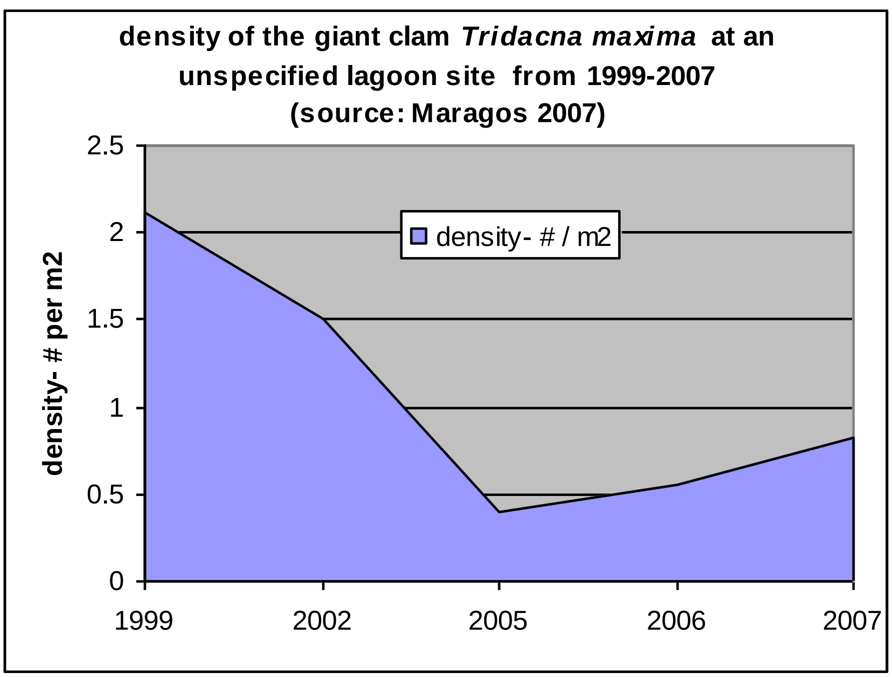


Figure 31. Example graph from one unspecified lagoon site depicting the response of giant clam populations from 1999-2007 (Maragos 2008).



Fish

Fish surveys were conducted by DMWR in 1995 and by CRED every 2 years since 2002. Using 1995 – 2006 data, they found that the fish community near the wreck site had far greater numbers and biomass of herbivorous fish than other sections of the fore reef (Schroeder et al. 2008). This was attributed to the bloom of cyanobacteria. And although the majority of the metallic debris had been removed by 2006, they pointed out that cyanobacteria remained high in areas with metallic remnants. With the completion of debris removal in 2010, algae on the fore reef has begun to recede. This is likely to lead to a change in the fish community. Because CRED has fish data from Rose Atoll from 2008, 2010 and 2012, FWS is beginning discussions with CRED to analyze this data for effects to the fish community related to the oil spill.

Future Restoration, Monitoring and Analysis

In September 2010, FWS completed the most important restoration action in the Restoration Plan, the removal of the metallic debris. FWS will continue monitoring multiple ecosystem variables until 2017 in order to document the effectiveness of the restoration action in restoring the ecosystem damaged by the spill **(Table 7).** Presently there are no visible pieces of ship debris remaining on the fore reef, reef flat or in the lagoon. In the unlikely event that a storm was to wash up any undetected pieces of debris, FWS will use the remaining contingency funds to remove them **(Table 8)**.

If after analysis of 2013 data we find that the recovery is not progressing at a reasonable rate, FWS will test secondary restoration actions to determine if we can speed up the recovery of the ecosystem. Such actions could include physically removing cyano-bacteria and transplanting coral and CCA **(Table 8)**.

There have been two developments making it easier for FWS to get to Rose Atoll more frequently. As of 2011, FWS has a Refuge Manager for Rose Atoll stationed in American Samoa, and there is a new charter company in American Samoa chartering smaller, less expensive vessels. These developments make it possible for more frequent monitoring trips to Rose Atoll, giving FWS the ability to collect more frequent data in order to track the recovery more closely.

We will begin acquiring satellite imagery on an annual basis. This will provide a clear visual record of the extent of the algae bloom, providing a complementary data set to on the ground monitoring.

Data Analysis in General

FWS has a backlog of data that needs to be analyzed and will hire a 3rd party with the necessary analytical skills to analyze the data and prepare it for publication. This will likely be a PhD. Student or a Postdoctoral fellow. Additionally FWS will work with NOAA CRED to conduct specific analysis of their extensive data set for Rose Atoll. CRED has been collecting data at Rose Atoll on a biennial basis since 2002 as part of their American Samoa Reef Assessment and Monitoring Program (ASRAMP). They have an extensive data set on corals, CCA, fish, and invertebrates that could be specifically analyzed to compare the ship wreck area of the fore reef to other areas. While CRED does most of their work between 20-60 feet, in April 2012 they worked with the Rose Atoll refuge manager to place Calcification Acidification Units (CAUs) which are used to measure the growth of CCA on the reef crest near the ship wreck and at an area up current from the wreck site. This will allow us to compare CCA colonization rates at the two sites.

Iron removal

It is possible but unlikely that debris will wash up on the shallow fore reef or reef crest during a storm. FWS will survey the SW arm fore reef and reef crest for new metal debris every 2 years and will remove any debris if found. If there is substantial debris FWS will contract a debris removal company.

Iron Monitoring

Because increased iron levels maintain the invasive species bloom caused by the spill, FWS will continue monitoring iron levels so we can compare changes in the biological community with changes in iron levels. We will collect iron data in 2013, 2015, and 2017.

CCA and Algae

FWS will conduct CCA / Algae surveys annually. FWS will hire a third party to analyze and prepare a report on the back log of data. CCA / Algal community changes will require multivariate analysis to compare patterns on the SW arm to patterns on the other arms. FWS will work with CRED to analyze CAUs, specifically looking at the effectiveness of restoration actions on Rose Atoll. If we do not see substantial recovery by 2013, FWS will look into efforts to physically remove algae, and transplant CCA.

Corals / Clams

FWS will continue to monitor the permanent transects established by Maragos to track changes in corals and giant clam abundance. FWS will work with CRED to have them analyze their data set to determine how effective restoration activities have been in restoring baseline conditions.

Urchins / Sea Cucumbers

FWS will conduct urchin / sea cucumber surveys annually and will hire a third party to analyze and prepare a report on the back log of data. The urchin data will need to be analyzed through time and compared to the cover of live CCA since it appears that the loss of holes near the wreck site from erosion of the reef platform is interacting with urchin mortality in a complex way. Analysis of the sea cucumber data will be attempted, but may be unreliable since data collection is very dependent on conditions that affect visibility at the time surveys are conducted.

Fish

FWS will work with CRED and DMWR to analyze fish data specifically looking at the effects of the oil spill and restoration actions on recovery of fish populations near the spill site.

Remote Sensing

Remote sensing is a very effective visual tool for documenting trends on the reef flat. Because there was no FWS staff in American Samoa at the time the Restoration Plan was written, remote sensing was considered as an alternative to annual monitoring. However, remote sensing is far more useful as a complementary technique to on the ground surveys. Now that FWS has a Refuge Manager stationed in American Samoa, and access to cheaper charter vessels, it is far easier to conduct more frequent monitoring.

FWS will purchase LiDAR data in order to have highly accurate elevation data of the reef crest. This will allow us to determine if several years of erosion without CCA growth has decreased reef crest elevation at the wreck site.

Reporting

FWS will provide a report to NPFC by January 31 of each year documenting activities of the previous year. At the end of the monitoring period in 2018 we will provide a final report to NPFC documenting the results of all restoration and monitoring activities that took place using NPFC funds.

Table 7. Schedule and budget of future monitoring actions at Rose Atoll. These are best estimates and are subject to change depending on availability of local experts and the charter vessel, as well as changing prices.

Year	7 day Charter Bonavista II	Iron Monitoring	Reef Flat Urchin / Algae Transects	Fore Reef / Lagoon Algae Transects	Giant Clam Coral transects	CRED analysis Fish Corals Algae	Contracted analysis and reporting	Satellite Imagery	Final Report	Total
Cost Per =	$13,000	$4,000	$10,000	$10,000	$4,000	$20,000	$10,000	$2,000	$2,000	
2012	1	1								$17,000
2013	2	1	1	1			1	1		$62,000
2014	1		1					1		$25,000
2015	2	1	1	1		1	1	1		$82,000
2016	2		1		1			1		$42,000
2017	2	1	1	1			1	1		$62,000
2018									1	$2,000
Totals	**$130,000**	**$16,000**	**$50,000**	**$30,000**	**$4,000**	**$20,000**	**$30,000**	**$10,000**	**$2,000**	**$292,000**

Table 8. Additional actions which may be necessary if additional pieces of debris wash up on the reef flat, or if cyanobacteria does not continue to decline on the reef flat and in the lagoon.

Year	7 day Charter MV Sili	7 day Charter Bonavista II	Salvage cleanup crew	Removal of cyano-bacteria	Transplant Corals	Total
Cost Per =	$60,000	$15,000	$30,000	$8,000	$8,000	
2012						$0
2013						$0
2014		1		1		$23,000
2015					1	$8,000
2016		1		1		$23,000
2017					1	$8,000
2018	1		1			$90,000
Totals	**$60,000**	**$30,000**	**$30,000**	**$16,000**	**$16,000**	**$152,000**

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